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BEHAVIORAL RESPONSES OF CARIBOU TO LOW-ALTITUDE JET AIRCRAFT

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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We evaluated the behavioral responses of free-ranging caribou (Rangifer tarandus granti) to low-level, sub-sonic jet aircraft overflights. Overflights were conducted by the U.S. Air Force in 1991 during late winter (April), post-calving (June), and the insect season (July-August). During three 7-10 day field sessions, we recorded the reactions of 268 groups of caribou to 159 overflights by A-10, F-15, and F-16 jet aircraft. Approximately 50% of the caribou showed some degree of overt behavioral response to the overflights, but only 13% of the overflights caused the animals to move. Activity budgets were compared between disturbed and undisturbed groups of caribou; no differences were evident in late-winter, but during post-calving and the insect seasons overflown animals spent less time lying and more time either feeding (post-calving) or walking (insect season). Daily distance traveled was compared for disturbed and undisturbed animals; no differences were evident during late winter and the insect season, but disturbed caribou traveled farther than did undisturbed caribou during post-calving. We concluded that behavioral impacts generally were mild, but that female caribou reacted to jet aircraft overflights by lying less and moving more, and that these responses were most prevalent in June when new born calves were present.

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INTRODUCTION

Background

Aircraft disturbance of northern ungulates has been a concern for over 20 years as biologists became aware of potential adverse effects of their own aerial surveys, increased recreational use of aircraft in remote areas, and resource exploration and development in northern regions (Klein 1973, Calef *et al.* 1976). Military training exercises also have increased in remote regions in recent years, and the effects of low-altitude overflights on wildlife, such as caribou (*Rangifer tarandus*), have caused concern among northern residents and resource agencies (Wadden 1989). This increased public concern coupled with National Environmental Policy Act (NEPA) requirements for environmental assessments of proposed military exercises prompted the U.S. Air Force (USAF) to convene a "Research Needs Workshop" in April 1988 on the "Effects of Aircraft Noise and Sonic Booms on Fish and Wildlife" (Asherin and Gladwin 1988). This workshop was jointly sponsored by the USAF and the U.S. Fish and Wildlife Service and was held to identify research needs, design research programs responsive to those needs, and rank the resulting proposed programs in terms of priority. This study was among the top five studies ranked by the workshop participants and was subsequently selected for funding by the USAF Noise and Sonic Boom Impact Technology (NSBIT) program. Caribou (*R. t. granti*) were selected for study primarily because detailed energetics models were available for this subspecies, and because the Delta Herd in Interior Alaska occurs near Eielson Air Force Base.

Potential impacts of aircraft disturbance to ungulates include displacement of animals from preferred range, negative energetic balance resulting from physiological and behavioral responses, disruption of breeding activities, lowered reproductive success, and subsequent demographic changes (Klein 1973, Wadden 1989, Harrington and Veitch 1991). There are few empirical data with which to address these concerns, however, because there have been relatively few studies that have quantified the effects of aircraft, particularly military aircraft, on wild, free-ranging animals (Manci *et al.* 1988).

Studies that have directly addressed some of these issues include investigations of the effects of disturbance by aircraft on behavior, physiology, and movements of mountain

sheep (*Ovis canadensis*; MacArthur *et al.* 1979, 1982; Krausman and Hervert 1983; Krausman *et al.*, in press; Bleich *et al.* 1990; Workman *et al.* 1992a), desert mule deer (*Odocoileus hemionus*; Krausman *et al.* 1986, Krausman *et al.* in press), elk (*Cervus canadensis*, Workman *et al.* 1992b), pronghorn antelope (*Antilocarpa americana*; Workman *et al.* 1992c), bison (*Bison bison*; Tempany *et al.* 1976, Fancy 1982), and caribou (Klein 1973; Davis *et al.* 1985; Gunn *et al.* 1985; Valkenburg and Davis 1985; Harrington and Veitch 1991, 1992). These studies have shown that disturbance by aircraft may result in increased animal movement and changes in habitat use (Krausman *et al.* 1986, Bleich *et al.* 1990), decreased frequency of nursing (Gunn *et al.* 1985), increases in heart rate (MacArthur *et al.* 1979, 1982; Workman *et al.* 1992a,b,c; Krausman *et al.* in press), and overt behavioral responses (Harrington and Veitch 1991).

Harrington and Veitch's studies (1991, 1992) have particular relevance to this study because they evaluated impacts of NATO military training flights on behavior, movements, and calving success on woodland caribou (*R. t. caribou*). Although they reported that short-term behavioral and energetic effects were minimal, they concluded that calf survival was affected by the frequency of exposure to low-altitude overflights during and immediately after calving. In contrast, biologists from the State of Alaska concluded that Delta Herd caribou have become habituated to aircraft disturbance (Valkenburg and Davis 1985) and that although the Delta Herd has been exposed to frequent low-altitude overflights by military and civilian aircraft for a number of years (more than any herd in Alaska), disturbance had not adversely affected productivity (Davis *et al.* 1985). These conclusions, however, were based on annual trends in the productivity of the Delta Herd, as well as other herds in Alaska that were not exposed to low-altitude overflights by military aircraft, rather than by any actual evaluation of the effects of overflights on individual animals. Currently, the Delta Herd is experiencing a population decline and numbers less than 35% of estimates for the late 1980s (Valkenburg 1992). In general, caribou population dynamics are poorly understood and often controversial, but the population decline of the Delta Herd has been monitored closely and evidence indicates that predation is a major factor for the decline (Valkenburg 1992).

Goals and Objectives

The goals of this research program were to quantify the behavioral responses of caribou to overflights by low-altitude, sub-sonic jet aircraft, and to incorporate these findings into a model that can predict the energetic and demographic consequences of repeated

overflights. In this report, we present the results of our field research on the behavioral responses of caribou to disturbance by jet aircraft. Results from experiments with captive caribou and reindeer at the Large Animal Research Station at the University of Alaska Fairbanks and modeling of energetic costs and demographic consequences of overflights will be presented in a separate report (White *et al*, in review). The specific objectives of the field research program were:

1) to measure the noise exposure experienced by caribou overflown by jet aircraft;

2) to record behavioral reactions of caribou to overflights by low-altitude jet aircraft by direct observation;

3) to record activity cycles and movements of caribou exposed to overflights by low-altitude jet aircraft using telemetry; and

4) to evaluate the behavioral responses of caribou to overflights as a function of noise exposure.

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METHODS

There were four separate periods of field activity for this project, one in 1989 and three in 1991. The 1989 field season was a reconnaissance-level effort that was designed to test techniques, equipment, and our ability to get biologists, jets, and caribou in the same place at the same time. Results of the 1989 field season were reported on at the Fourth North American Caribou Workshop in St. John's Newfoundland in 1989 (Murphy *et al.* 1991); this paper is provided in Appendix A.

There were three 8-10 day periods of data collection in 1991:

Late Winter (30 March - 6 April 1991)

Post-calving (7-16 June 1991)

Insect Season (26 July - 3 August 1991)

During the week prior to each sampling period, reconnaissance surveys were flown to determine where the Delta Herd caribou were distributed over its 9600 km^2 range (Davis *et al.* 1985). Animals that had been radio-collared previously by the Alaska Department of Fish and Game (ADFG) were located and a general impression of herd distribution was ascertained. A study area and a location for our field camp then was selected based on the distribution of caribou and logistical considerations. Locations of the study areas differed among sampling periods, but always were located on the north side of the central Alaska Range between the Parks and Richardson highways (64 ° 14' N, 148° 34' W; 63° 35' N, 146° 14' W; Figure 1).

For each sampling period, it was necessary to capture and instrument caribou with radio collars and noise monitors prior to the onset of data collection. A team of three scientists, using both helicopter and fixed-wing aircraft, flew to the designated study area at least two days prior to the beginning of the overflight period and captured and instrumented two groups of up to five adult female caribou by darting from a helicopter. Darts contained a mixture of carfentanil and xylazine.

One group of five caribou was scheduled to be overflown by the jet aircraft and was designated the "treatment" group. The other five animals were captured at least 16 km away from the treatment group and were designated the "control" group, which ostensibly would not be exposed to overflights. All captured animals were instrumented with *Wildlink* collars (St. Paul, MN) that were equipped with VHF radio transmitters and an

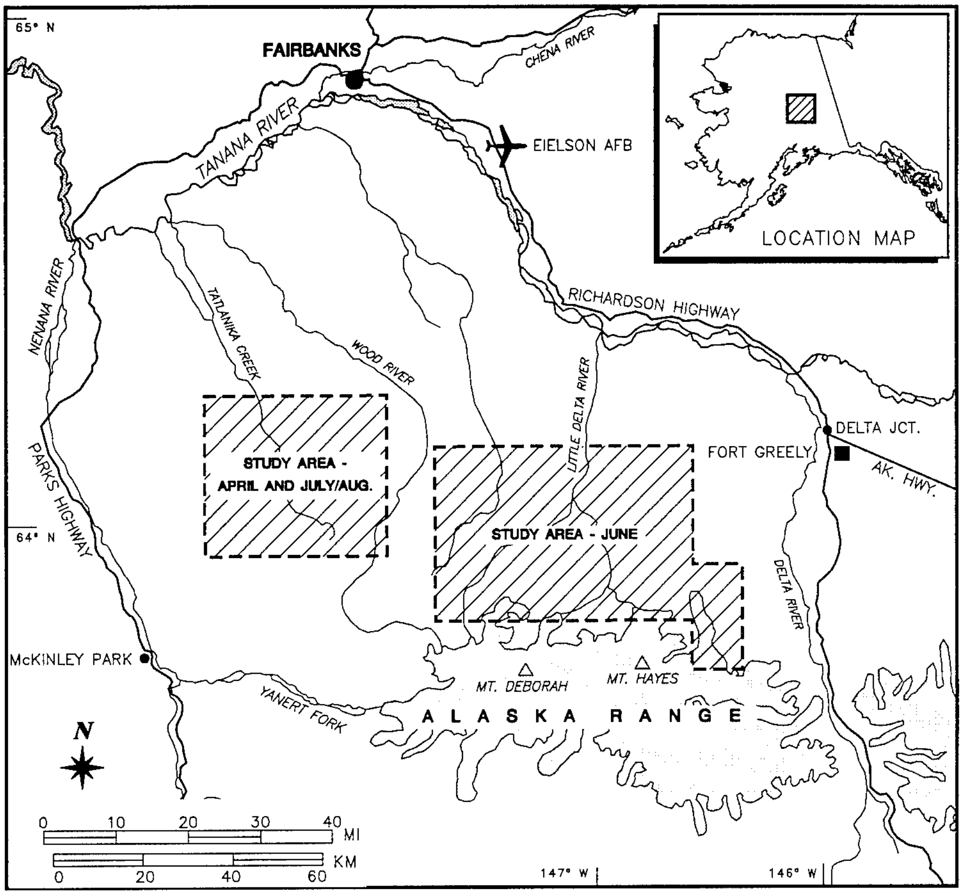

Figure 1. Location of study areas in Alaska used to observe the effects of low-altitude overflights by military jet aircraft on caribou, 1991.

activity counter (see details below). The five animals in the treatment group also were outfitted with Animal Noise Monitors (ANMs; see details below). Each ANM was protected by a cordura pouch with an aperture for the microphone. The pouches were affixed to the top of *Wildlink* collars so that the microphones would be exposed directly to the aircraft noise source. To maintain the proper orientation of the unit on the nape of the caribou's neck, a mounting system consisting of lead-shot counterweights and an aluminum brace was custom-fitted to each animal. Care was taken to insure uniform tightness and positioning of the collars, because collar movement can affect the activity counters. After collaring, caribou were given an intramuscular injection of penicillin, a topical application of antibiotic powder, and the reversing agents naloxone and yohimbine. At the completion of each sampling period, each collared animal was located and the collar was dropped from the animal by transmitting a radio signal that caused a connecting bolt to release. The collars then were retrieved by helicopter. All animal

capture and handling procedures were approved by the UAF Animal Care and Use Committee (Project No. 90-011).

The field crew for data collection included three biologists, an acoustician, a Ground Forward Air Controller (air controller), a fixed-wing pilot, and a helicopter pilot. Days scheduled for overflights began with a radio-tracking flight to locate all of the instrumented animals in the treatment group. A decision then was made as to where the observers would be positioned, and a helicopter shuttled the biologists, the acoustician, and the air controller to the selected site. Helicopter disturbance was minimized by carefully selecting landing sites and approaches that were out of view from the caribou. After disembarking from the helicopter, observers hauled their equipment to the observation site.

Once on site, the air controller set up radio equipment and waited to hear from USAF pilots in the vicinity. After radio contact was established, the air controller notified the pilots of our location and then directed the jets along specific flight paths requested by the biologists. In most instances, the pilots were directed to fly directly over the caribou at 33 m (100 ft) above ground level (agl) at high or full power setting. Pilots also were instructed to maintain at least 5-min intervals between multiple overflights.

One biologist worked closely with the air controller (e.g., requesting specific flight paths and recording flight data relayed from the pilots) and was responsible for precisely mapping the locations of caribou and the path of jets for each overflight. Two other biologists recorded the behavior of caribou before, during, and after each overflight. The acoustician recorded data on weather, flight characteristics, and tended noise monitoring equipment. The helicopter pilot stood by to move the team if necessary.

Noise Exposure

Noise generated by jet aircraft was measured using prototype ANMs and stationary acoustical noise monitors. Because the primary objective for noise monitoring was to measure noise exposure experienced by caribou overflown by jet aircraft, it was necessary to design equipment capable of accurately measuring noise exposure for free-ranging animals. The prototype ANMs were developed specifically for this program and represent the first time that a measurement of noise exposure was made on free-ranging animals in their natural habitats.

The ANMs are capable of collecting noise exposure information over long periods of time (up to six months) under a variety of environmental conditions. An ANM weighs about 450 g and is mounted on a collar that also carries a radio transmitter used to locate the animal. Longevity of the device is attained by keeping the unit in a semi-dormant state until a series of adjustable thresholds have been exceeded Thus, only events associated with aircraft overflights were measured and battery life was optimized. ANMs measure and calculate a number of acoustic parameters, such as a Maximum Noise Level (L_{max}) and Sound Exposure Level (SEL), using both A- and C-weighted scales. This information, together with date, time, and some activity data, was stored in memory.

Each ANM was powered by three, one-half C-sized lithium cells for data collection and a lithium button cell for data storage. A *Sennheiser* Model KE 4-211-2 mini-capsule microphone treated with a chemical water-proofing compound was used to record aircraft noise events.

One of the hazards of outdoor noise measurement is the environment, particularly the presence of wind conditions. Solutions to this problem include using large wind screens that can reduce the effect of wind noise under some conditions, and avoiding measurements when the prevailing wind is too high. The ANMs, which were not accessible after deployment, incorporated both options. When the wind conditions were mild, a small wind screen affixed to the microphone provided the necessary protection. When wind conditions were high, a pre-set threshold system allowed some protection against false readings and prevented exhaustion of the battery.

During the windy late-winter sampling period, two ANMs were programmed with a noise event threshold of 90 dBA that had to be exceeded for at least two seconds, and three ANMs were programmed with a noise event threshold of 85 dBA that had to be exceeded for more than two seconds. During the insect season and post-calving, all ANMs were programmed to record all noise events that exceeded 85 dBA for more than two seconds.

There were several technical problems associated with the use of the prototype ANMs. Batteries were the primary problem, especially during the late-winter sampling period, although some units were problematic throughout the study. The ANM housing limited the size of the batteries, which discharged in the cold temperatures on several occasions. Another problem, inherent to the nature of prototypes, was the level of reliability of the units; some units consistently functioned well and some units consistently had problems.

A secondary approach used stationary acoustical noise monitors located in the general areas of the overflights to record noise at fixed positions. These measurements were used as a backup to the ANM data and as a means to verify the performance of the ANMs.

The secondary measurement method relied on several *Larson Davis* Model 870 Precision Integrating Sound Level Meters (LD 870 equipped with LD 900B microphone preamplifiers, *Brüel and Kjær* Model 4155 Electret microphones, wind screens, and external 12V batteries). Attempts were made to locate this equipment as closely as possible to the instrumented animals. These secondary noise measurements permitted inference of the noise exposure of animals at a fixed location. In practice, the caribou often moved between the time when the instruments were deployed and when the overflights occurred.

These fixed-site monitors were programmed to record Equivalent Sound Level (L_{eq}) on an hourly basis and to record single noise events that exceeded 70 dBA. Single event noise measurements included the maximum decibel level achieved during the overflight (L_{max}) and SEL. SEL is a measure of the total amount of acoustical energy generated during an event calculated by logarithmically integrating the magnitude over the time period of the event.

A-weighted SEL in decibels (dBA) was the noise descriptor selected for the analysis of the noise "dose" received by the caribou. For each aircraft overflight, the SEL measured by the ANMs was used to describe the noise exposure of an individual caribou and/or groups of caribou that contained instrumented animals. For caribou for which noise measurements from ANMs were not available the *OMEGA* 14.6 Aircraft Noise Prediction Program developed by the Air Force Occupational Environmental Directorate Bioenvironmental Engineering Division, Noise Effects Branch (AL/OEBN) was used to compute the estimated SEL. Variables required to estimate SEL using this program included aircraft type, number of aircraft, flight speed, power setting, and slant range (i.e., line of sight distance) from the aircraft to the caribou. Slant ranges calculated for animals that were not directly observed may have been inaccurate because of poor temporal correspondance between the time when the telemetry location was fixed and when the overflights occurred.

Prior to analysis, SELs were adjusted using correction factors that were calculated for each season and aircraft type. These correction factors were calculated by averaging the difference between estimated and ANM-based measurements for individual overflights.

In order to estimate daily noise exposure for each animal, a Time-averaged Sound Level (L_T) was calculated using the following formula:

$$L_T = 10\log_{10}\left[\frac{1}{T}\sum_{i=1}^{N} 10^{SEL_i/10}\right]$$

where SEL_i is the Sound Exposure Level of the *i*th event in a series of *N* events over the time period *T* (ANSI S12.40-1990). L_T, the number of overflights greater than 85 dBA, and the loudest overflight of the day were determined for each treatment animal for each day of the study and used as independent vaiables in regression analyses (see below).

Instantaneous Reactions

Instantaneous reactions of caribou group(s) under direct observation were recorded for each overflight. Numbers of caribou engaged in each activity category (i.e., feeding, lying, standing, walking, alert, and running) were recorded before, during, and after each overflight. In addition, the distance moved and the duration of disturbance behaviors were recorded following each overflight. Duration of a disturbance event was measured by assessing the behavior of the most reactive animal in the group under observation. Alert postures, walking (if initiated by the overflight), and running were recognized as disturbance behaviors, and a reaction was considered ongoing until all members of the group had ceased disturbance behaviors and resumed undisturbed behaviors (e.g., feeding, lying).

Similarly, distance moved in response to overflights was based on the group member that moved the maximum distance. Distance moved was measured only when there was clear evidence of a direct response to the aircraft, and was not measured for animals that were moving prior to an overflight and merely continued walking at the same rate after the overflight. Unusual behaviors also were noted.

Comparisons of instantaneous reactions among types of aircraft and among seasons were performed using analysis of variance (ANOVA). To examine relationships between decibel levels of overflights and the instantaneous reactions of caribou, linear regression models were used to determine if the duration of reactions or distance moved varied as a function of SEL.

Activity Budgets

Activities of caribou were recorded by two techniques: focal-animal and scan sampling (Altmann 1974). When possible, a caribou with an ANM was selected as the focal animal and a continuous log of the activity was recorded on an *Epson* HX-20 lap-top computer with a customized BASIC program. Monitoring began as soon as the observers were situated each morning and continued until the animal moved out of site or until termination of sampling at the end of the day. If the focal animal moved away, another ANM animal was selected or the team moved to a new location where either the original focal animal or a new animal could be observed. If possible, the focal animal was observed for at least one hour after the last overflight of the day. Activity categories for both focal and scan sampling were: feed, lie, stand, walk, alert, and run. The BASIC program was written so that a file marker could be recorded at the instant that a jet passed over the focal animal.

Scan sampling was used to monitor the activity of entire groups of caribou. The group selected usually included a focal animal. Activity scans were taken every 5-min; an alarm watch was used to prompt the observer. Other information recorded included number of animals, sex and age composition, and movements of the group.

Activity budgets were calculated in four steps: 1) the number of caribou engaged in each activity was transformed to a percentage for each activity scan; 2) each scan was classified as either that of a group of caribou that had been "recently overflown" or "not recently overflown"; and 3) a mean percentage was calculated for each activity category for caribou that had recently been overflown and for caribou that had not been recently overflown. Activity budgets for recently overflown and not recently overflown caribou then were compared for each season using a 2-way ANOVA. Prior to testing, percentage data were normalized using the arcsine square root transformation (Steele and Torrie 1980).

Two definitions were used to classify caribou as either recently overflown or not recently overflown. For one analysis caribou were classified as recently overflown if there had been an overflight during the previous hour. For a separate analysis, caribou were classified as recently overflown if there had been a flight during the previous 15-min period.

Activity Cycles

The *Wildlink* collars were programmed to record and sum activity at 60-min intervals. Activity was recorded by a mercury tilt switch that registered a count (i.e. activity count) each time the collar was tilted. These collars, which can store up to 36 intervals of activity data, were interrogated remotely and "downloaded" from a fixed-wing aircraft every 18 h during late winter and every 24 h during post-calving and the insect season. A triggering signal activated the collar, which responded by transmitting stored data (i.e. activity counts) in an audio binary code. The binary code was received using a *Telonics* receiver, recorded by hand, and later translated (Mech *et al.* 1990, Kunkel *et al.* 1991). Locations of collared caribou were recorded on 1:63,000 topographic maps each time activity data were downloaded.

There were a number of technical problems with the *Wildlink* collars. Three of nine VHF transmitters malfunctioned during late-winter leaving five animals in the treatment group, but only one animal in the control group. Nine collars were deployed during the insect season, four on animals in the treatment group and five on animals in the control group. One collar on an animal in the control group failed three days after the start of the sampling period, and another control animal wandered out of range and was not located until three days before the end of the sampling period; these animals were not used in the analyses. Ten collars were deployed during post-calving. Three of five caribou in the control group wandered into the treatment area and were exposed to overflights by low-altitude jet aircraft. Thus, eight animals were overflown and only two animals were not exposed to overflights during this sampling period.

Activity monitoring systems based on tilt-switch technology are not capable of discriminating between specific activities (e.g., standing, feeding, walking). They are, however, capable of accurately depicting active and resting bouts, and these were recorded in half hour (late-winter) or hourly (post-calving and insect season) intervals. These data then were summarized over 24-h periods for analysis. During the late winter sampling period, the data only could be summarized over a 21-h period because of gaps in downloading the data in the field. The 3-h deficit for each animal essentially was one active period, however. This 3-h active period was added to the data set for graphical representations, but statistical analyses were conducted on the 21-h data set.

The relationship between activity counts recorded by *Wildlink* collars and caribou behavior was evaluated using captive male and female caribou at the Large Animal

Research Station, University of Alaska Fairbanks. Kitchens *et al.* (1993) documented close agreement between activity counts, energy expenditure, and observed activity of captive caribou. Equations developed from this work on captive animals were used to interpret activity counts collected on wild caribou. Of specific importance to the results presented in this report is the concept of "resting threshold." Using data from captive caribou, the level of activity counts below which an animal was resting was determined:

$$\text{resting threshold} = 0.20 \times \text{largest hourly activity count of the season.}$$

Thus, if a hourly activity count of a wild caribou was greater than the resting threshold, the animal was considered to be active during that hour. Conversely, the animal was considered to be resting if the hourly activity count fell below the resting threshold.

The resting threshold was established to partition each day into resting and active bouts for each of the animals equipped with *Wildlink* collars (Figure 2). Thus, an active bout was defined as the sum of consecutive one-hour intervals during which activity counts exceeded the resting threshold. The number of resting and active bouts per day, the mean length of resting and active bouts per day, the daily time spent resting and active, and the overall daily activity level (i.e., total activity counts per day) then were calculated. For comparisons of treatment and control animals, daily activity counts were standardized to the proportion of total counts per season (i.e., daily activity counts / total counts per season) because of suspected between-collar variability.

Activity cycles were analyzed by comparing treatment and control groups and by multiple-regression analysis for treatment animals. Comparisons of treatment and control groups were made after verifying that individual animals actually had been overflown on a given day. For example, if an animal from the control group moved into the overflight zone and was exposed to overflights exceeding 85 dBA, it was classified as a "treatment" animal for that day (this occurred 11 times, 10 during post-calving). Conversely, if an animal from the treatment group was not exposed to overflights on a given day, it was classified as a "control" animal for that day (this occurred frequently because there were numerous days with no overflights). Comparisons between treatment and control groups were made for number of active and resting bouts per day, mean length of active and resting bouts, daily time spent active and resting, and proportion of total counts per season. ANOVA was used for these comparisons and significance was assessed at $\alpha = 0.05$.

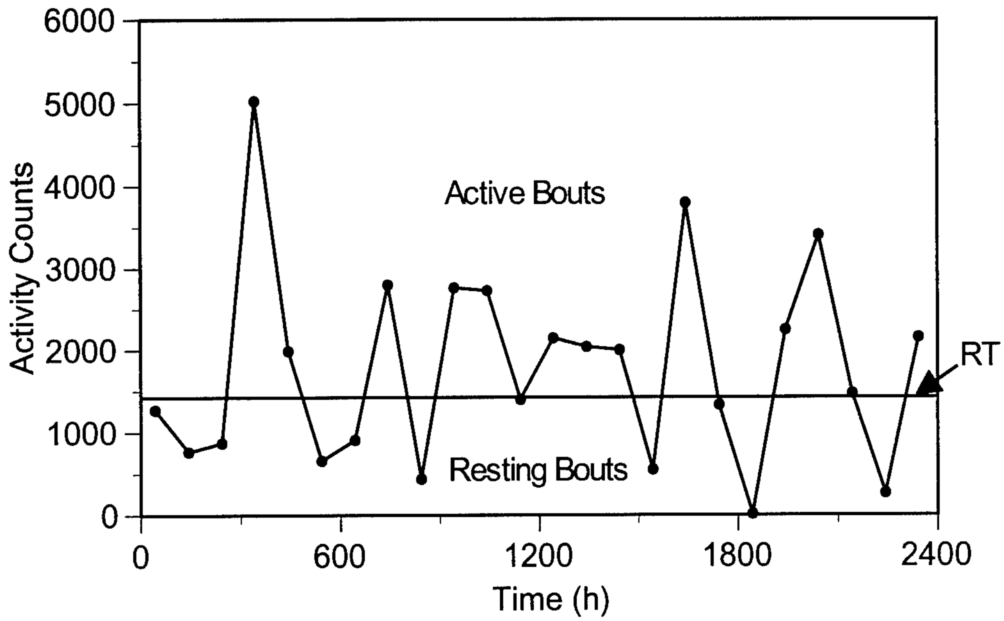

Figure 2. Example of 24-h activity counts plotted on an hourly basis for caribou in Alaska, 1991. The resting threshold (RT) differentiates between active and resting bouts.

Movements

Locations of instrumented caribou and caribou under direct observation, together with the route of each overflight were plotted on digitized study area maps using *Atlas* GIS (Geographical Information System) software (Figure 3). Spatial analyses were performed to determine the distance traveled between daily (24 h) radio telemetry locations for each animal, and the slant range from each instrumented caribou to each overflight route. That is, a linear, two-dimensional distance between telemetry locations recorded at 24-h intervals was calculated for both treatment and control animals.

Daily distance traveled by caribou was compared (one-way ANOVA) between treatment and control animals using the same criteria described above to assign animals to the two groups (i.e., at least one overflight $\geq$ 85 dBA on a given day for inclusion in the treatment group). Daily distance traveled was not normally distributed and, therefore, was ranked prior to statistical analyses.

Regression Models

To evaluate whether specific aspects of noise could be identified as influencing activity cycles and daily movements of caribou, simple linear regression models (*SAS*—All Possible Models) were developed using data from treatment animals. Specifically, we attempted to determine which noise variables, if any, explained variations in 1) number of daily resting bouts, 2) mean length of resting bouts, 3) daily time spent resting, and 4) daily distance moved. The independent variables considered were: 1) number of overflights $\geq$ 85 dBA, 2) loudest overflight each day, and 3) average noise exposure level for the treatment day (L_T). A correlation matrix was produced to determine the extent of collinearity among the independent variables. Only resting variables were considered because they essentially are the reciprocal of the active variables, because time spent resting per day is the primary variable used in modeling the population-level effects of low-altitude jet aircraft overflights on caribou, and because of the need to consider simultaneous confidence intervals for most of the models. That is, sequential Bonferroni corrections (whereby α was divided by the number of comparisons made) were required for all models generated from data from activity counts because of the lack of independence between models (Neter *et al.* 1985). Thus, an overall confidence level was assigned to the regression models for each season, and the initial α level of 0.05 was divided by three (i.e., three resting variables) and significance was assessed at $\alpha = 0.02$. Bonferroni corrections were not required for daily movements because they were not calculated from activity counts.

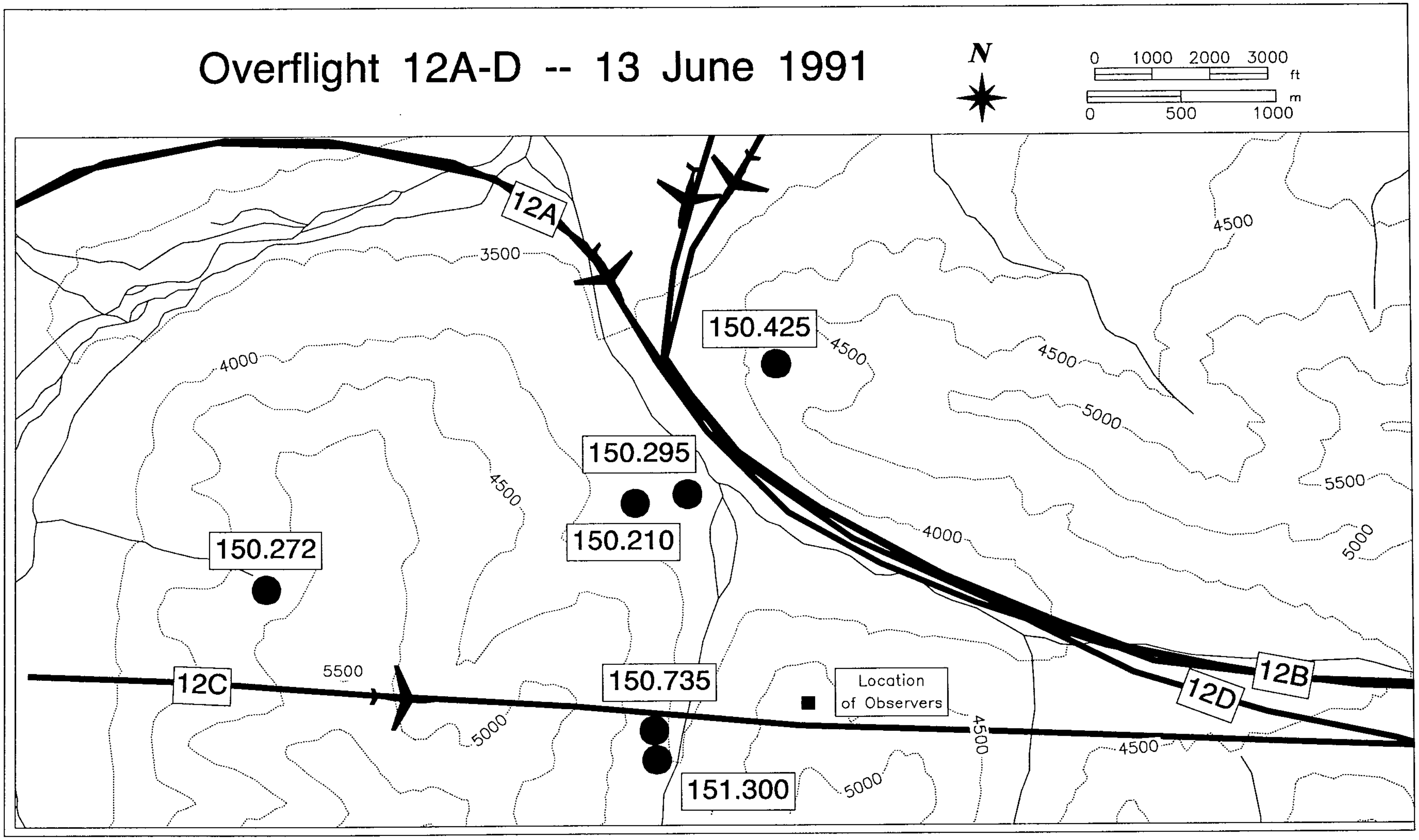

Figure 3. Example of GIS output depicting locations of the observation team, collared caribou, and flight paths of military jets in Alaska, 1991.

RESULTS

Noise Exposure

Caribou were exposed to a total of 159 overflights by jet aircraft during the three sampling periods. Of these jets, 94 were A-10s, 61 were F-15s, and 4 were F-16s. During late winter and post-calving, only A-10 and F-15 aircraft were available. During the insect season, A-10s, F-15s, and F-16s were used. Several groups often were observed simultaneously; therefore, 268 groups of caribou were observed during the 159 overflights.

The mean slant distance (i.e., the line-of-sight distance between the aircraft and the caribou) for all overflights was 756 m (Table 1). A-10s were able to provide the closest overflights, followed by F-15s, and F-16s (Table 1). A-10s also were the slowest of the three aircraft, with airspeed averaging 502 km/h, whereas F-15s averaged 642 km/h, and F-16s averaged 806 km/h (Table 1).

SELs were measured or estimated for each overflight. For animals under direct observation, SELs ranged from 46 to 127 dBA; the maximum noise exposure was produced by an F-15 flying at a slant distance of 106 m from the caribou. The mean SEL for all 159 overflights was 98 dBA (Table 1). F-15s produced the greatest SELs (mean = 103 dBA), followed by F-16s (mean = 96 dBA) and A-10s (mean = 95 dBA).

The majority (> 70%) of the overflights that we observed resulted in SELs between 80 and 100 dBA (Figure 4). Forty-four percent of the overflights fell in the 90 to 100 dBA range. Less than 10% of the overflights exceeded 110 dBA.

Instantaneous Reactions

For all overflights, 49% of the caribou showed no overt behavioral response, 31% became alert, 6% stood up from a lying posture, and 13% moved in response to the jets. Responses to F-15s were significantly stronger ($p \leq 0.05$) than those recorded for A-10s and F-16s (Figure 5a; Appendix B). For F-15s, significantly more groups responded and became alert when overflown. No differences in reactions among sampling periods were detected, however (Figure 5b; Appendix B).

Table 1. Flight characteristics and estimated Sound Exposure Levels (SEL) of low-altitude overflights of caribou by military jet aircraft in Alaska, 1991.

		Slant Distance (m)		Airspeed (km/h)		SEL (dBA)		
Aircraft	Season	Mean	SE	Mean	SE	Mean	SE	*n*
A-10	Late winter	375	28.4	470	3.8	99	1.1	77
	Post-calving	448	55.0	530	7.8	94	1.0	66
	Insect	749	221.9	526	12.0	90	2.5	24
	All	457	101.8	501	7.9	95	1.5	167
F-15	Late winter	538	76.4	659	23.6	106	2.3	28
	Post-calving	1606	330.5	560	50.4	96	1.1	27
	Insect	1414	308.3	693	8.9	105	2.0	34
	All	1197	238.4	642	27.6	103	1.8	89
F-16	Insect	1647	244.7	807	22.0	96	3.0	12
All		756	180.7	562	18.3	98	1.8	268

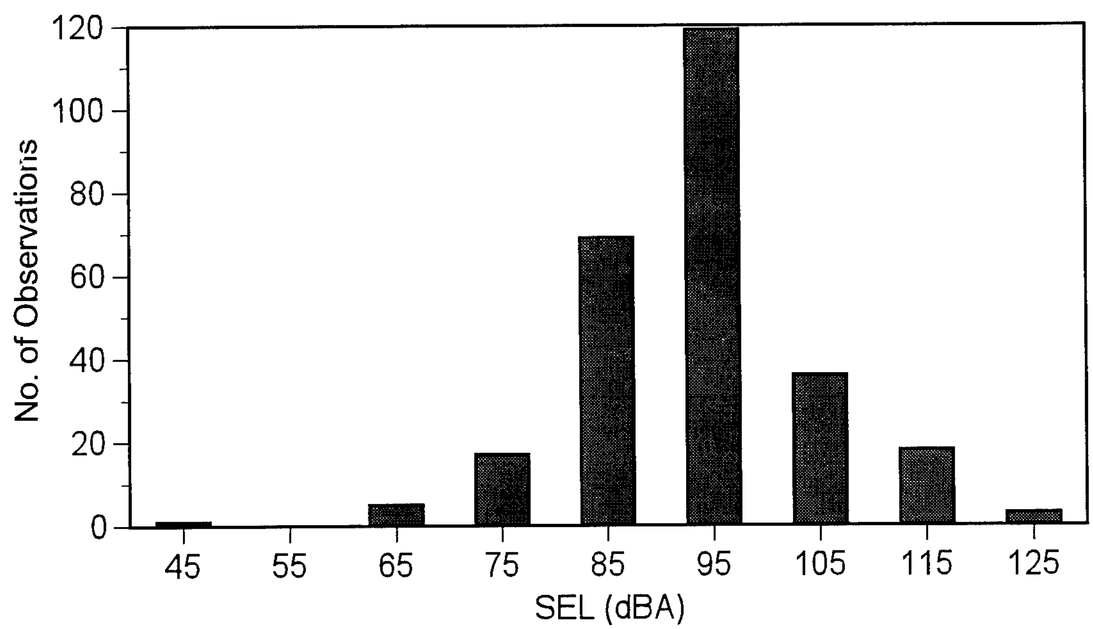

Figure 4. Number of observations of caribou at various Sound Exposure Levels (SEL) recorded during overflights by military jet aircraft in Alaska, 1991.

Linear regression was used to examine relationships between the decibel level of overflights and the reactions of caribou (i.e., to test if the duration of instantaneous reactions or distance moved by caribou in response to the overflights varied as a function of SEL). The models indicated a weak relationship between SEL and both of the response variables (SEL vs. distance moved, $r = 0.065$, Figure 6a; SEL vs. duration of reaction, $r = 0.018$, Figure 6b; Appendix B). These models also were run using data only from the ANMs to determine if the models improved if only directly measured noise data were used. When duration of reaction was modeled, the amount of variation accounted for by the ANM data ($r = 0.35$) was an increase over the model run using the entire data set; however, neither model explained a significant amount of the variation. For the distance moved model, using only ANM data set did not improve the model ($r = 0.14$).

Data from activity scans were used to compare the proportion of animals engaged in each activity for scans made during the 5-min period before overflights versus those scans collected during the 5-min period immediately following overflights. These tests were performed separately for each season and each activity category and there were no significant differences ($p \leq 0.05$) in the proportion of animals performing various activities before versus after overflights (Figure 7; Appendix B).

Activity Budgets

Activity budgets were calculated for groups of caribou that had not been overflown during the previous 60-min period, and these were compared with those of animals that had been overflown (Figure 8a; Appendix B). During late winter, animals that had been overflown during the previous 60-min period fed significantly more ($p = 0.024$) and rested (i.e., lying) less ($p = 0.066$) than did animals that had not been overflown. During post-calving, we detected no significant differences between animals that had been overflown during the previous 60-min period and animals that had not been overflown. During the insect season, animals that had been overflown during the previous 60-min period rested significantly more ($p \leq 0.001$) and stood significantly less ($p \leq 0.001$) than did animals that had not been overflown (Figure 8a).

Activity budgets also were calculated for groups of caribou that had not been overflown during the previous 15-min period, and these were compared with those of animals that had been overflown. During late winter, no significant differences were found between the activity budgets of caribou that had been overflown recently and caribou that had not been

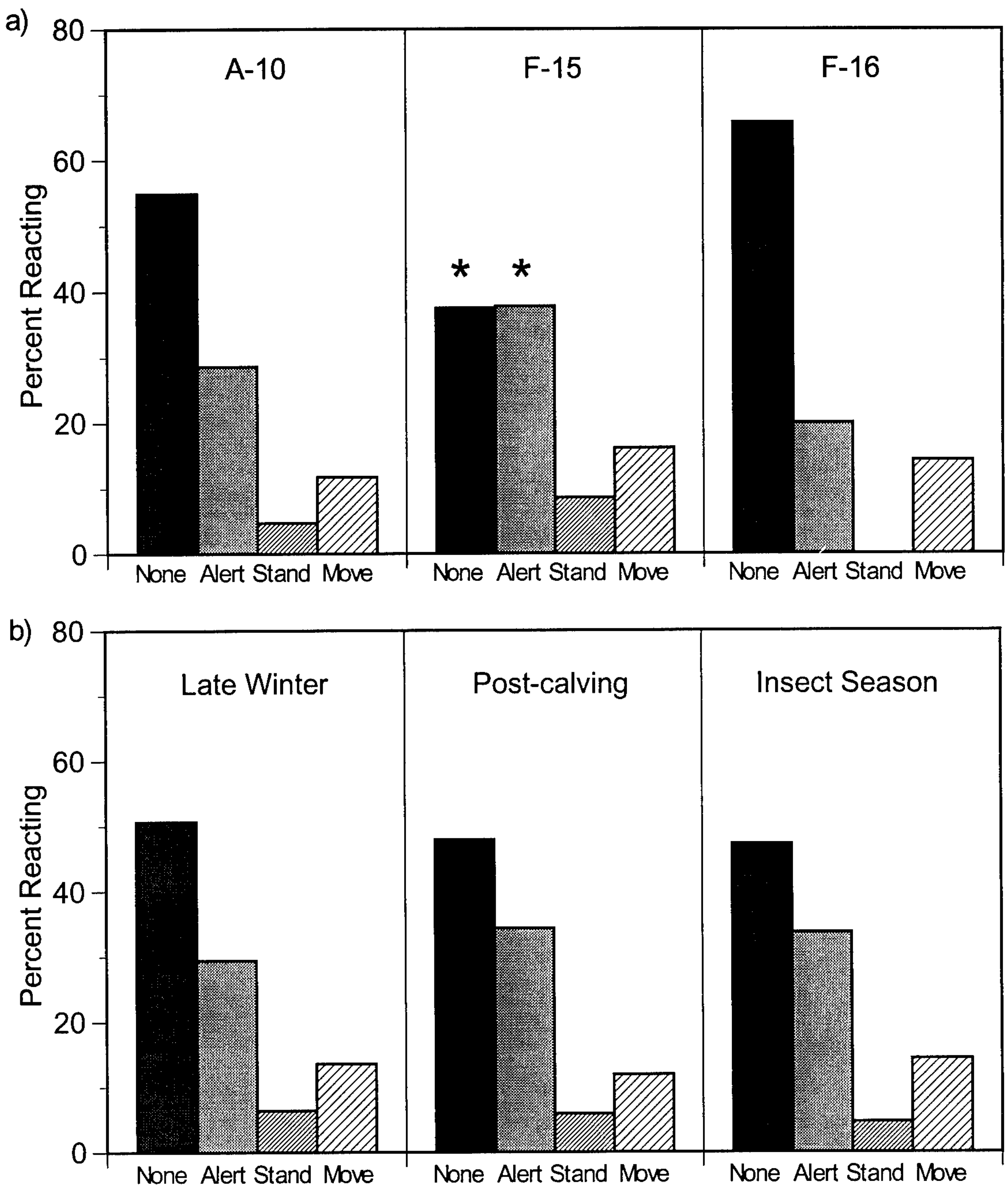

Figure 5. Percentage of caribou exhibiting various instantaneous reactions to overflights by military jet aircraft by a) aircraft type and by b) season in Alaska, 1991. Significant ($p < 0.05$) differences among types of aircraft or seasons for a particular activity are noted by an asterisk.

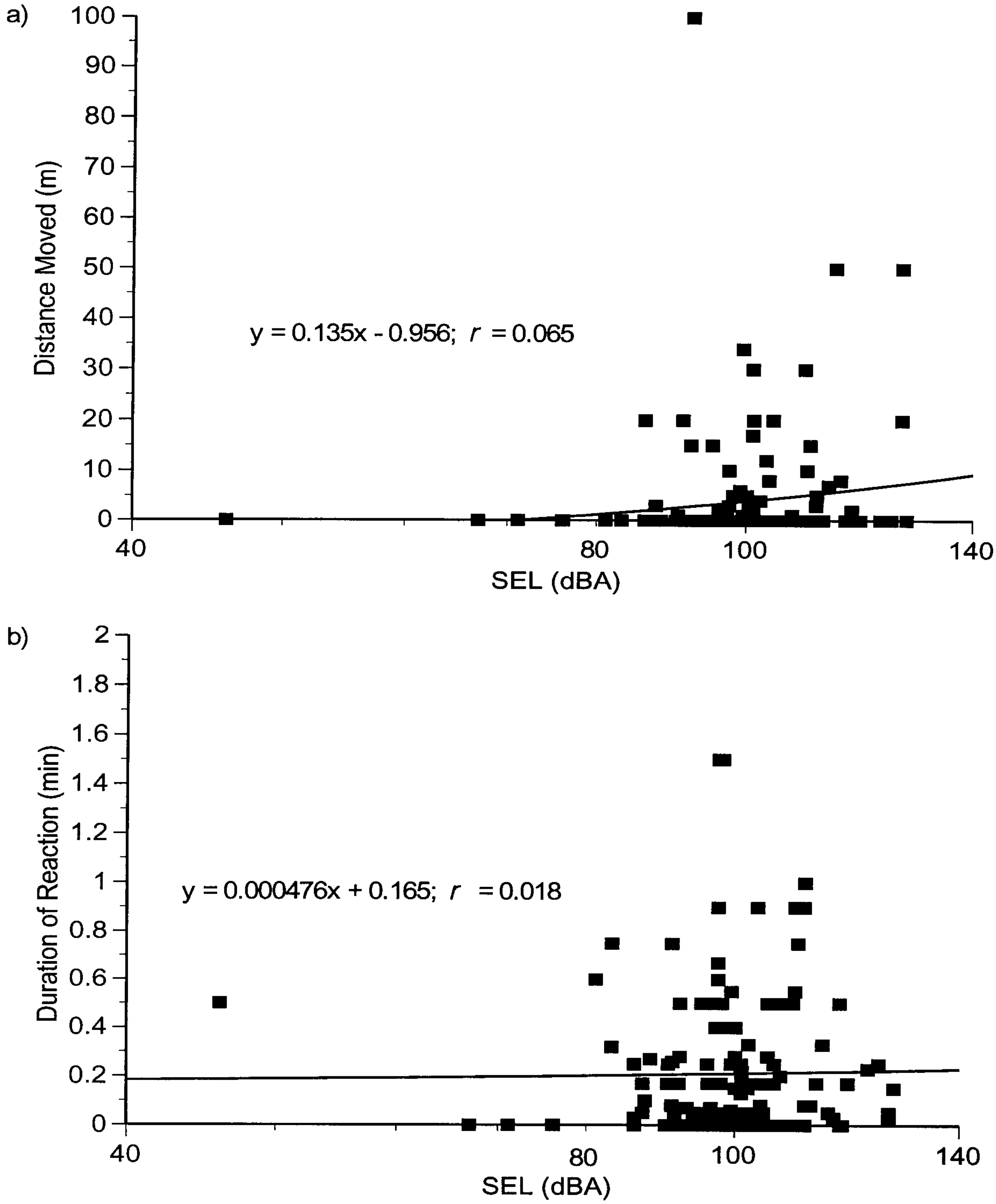

Figure 6. Linear regression plots and equations for a) Sound Exposure Level (SEL) and distance moved and b) SEL and duration of reaction for caribou reacting to overflights by military jet aircraft in Alaska, 1991.

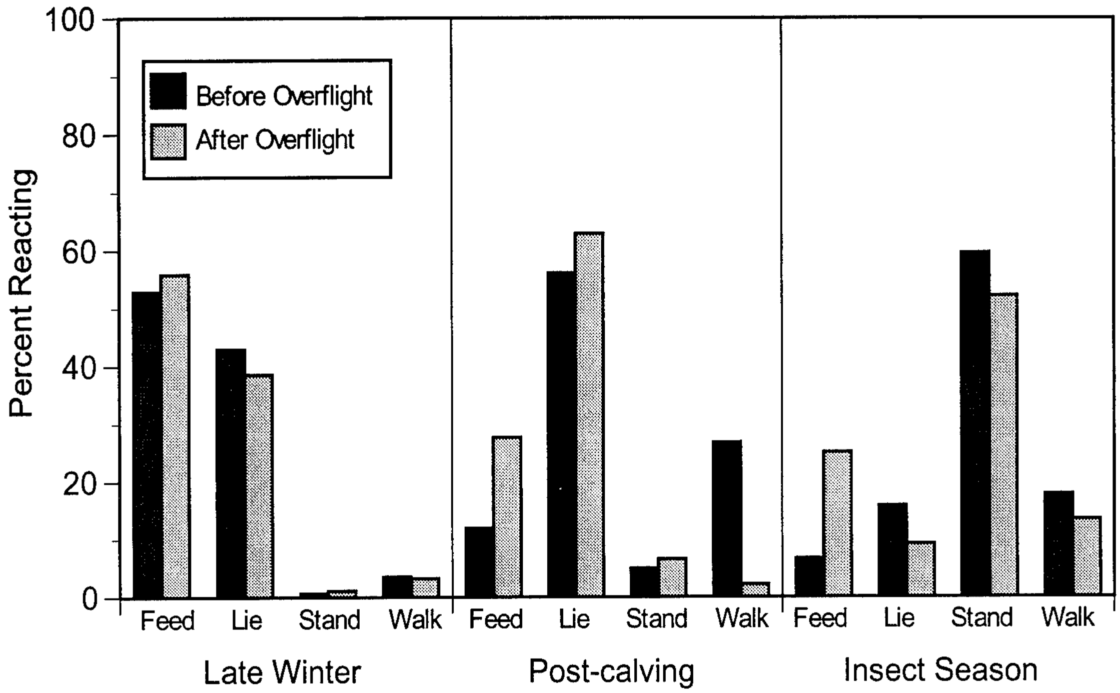

Figure 7. Seasonal comparison of activity budgets of caribou based on activity scans collected during 5-min period before an overflight and scans collected during 5-min period after an overflight in Alaska, 1991.

overflown (Figure 8b; Appendix B). During post-calving, however, there were significant differences between the two periods in the percentage of time spent feeding ($p \leq 0.001$) and resting ($p = 0.001$); caribou that were overflown recently spent more time feeding and less time lying than did caribou that had not been overflown. Similarly, during the insect season, caribou that had been overflown recently spent less time lying ($p \leq 0.001$) and more time standing ($p = 0.014$) than did caribou that had not been overflown (Figure 8b; Appendix B).

Activity Cycles

The number of resting bouts per day for animals in the control group ranged from 3.5 to 4.2 during the three sampling periods (Figure 9a). Caribou in the treatment group had significantly more ($p = 0.05$) resting bouts per day during late winter than did caribou in the control group, whereas there were no differences within the other two sampling periods (Figure 9a; Appendix B). The number of active bouts per day for animals in the control group ranged from 3.8 to 4.8 (Figure 9b). Number of active bouts recorded for animals in the treatment group did not differ during any of the sampling periods (Figure 9b; Appendix B).

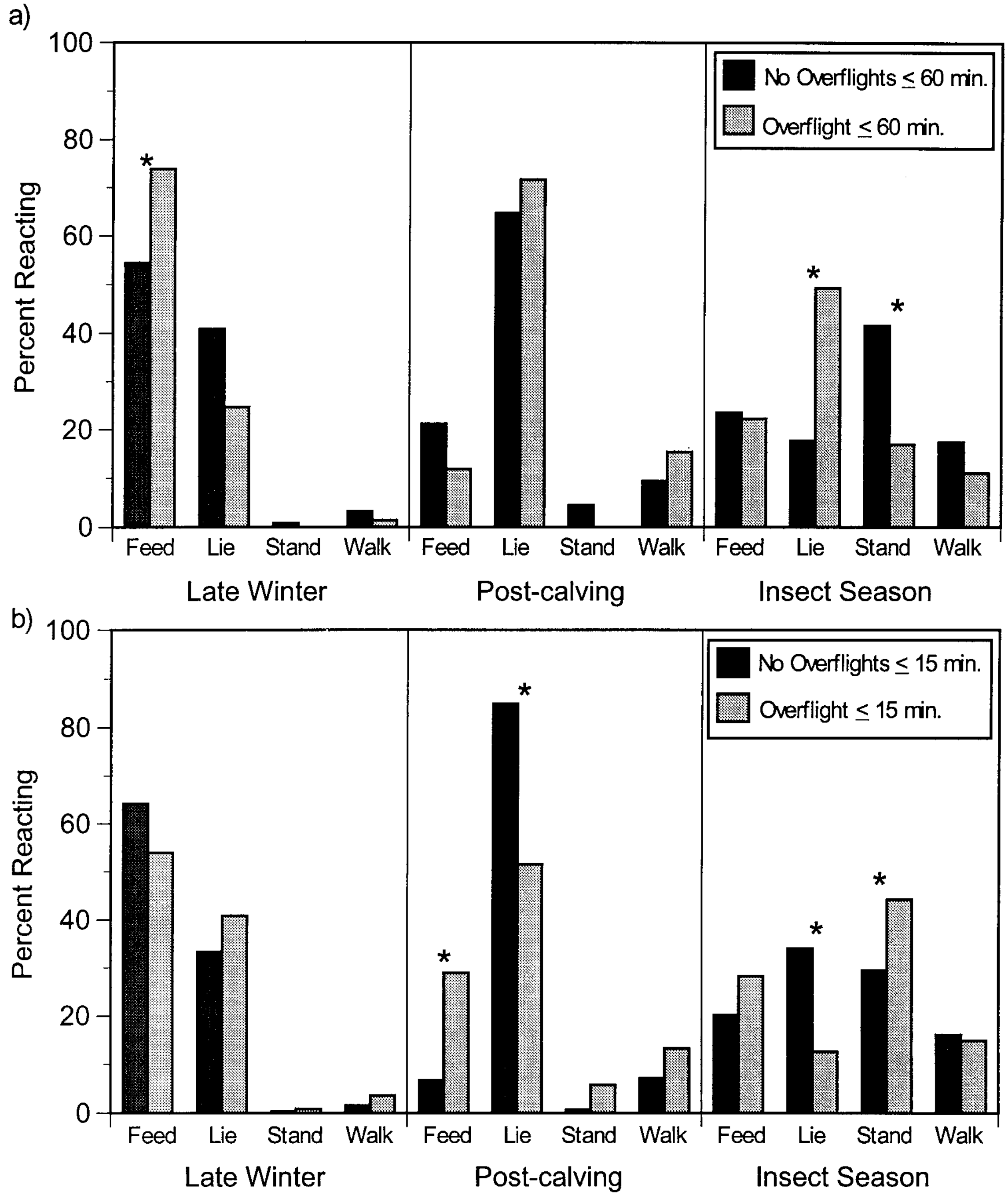

Figure 8. Seasonal comparison of activity budgets of caribou that had been overflown by military jet aircraft during a) the previous 60-min and b) 15-min periods and caribou that had not been overflown during the previous 60-min and 15-min periods in Alaska, 1991. Significant ($p \leq 0.05$) differences between caribou that were and were not overflown for a particular activity are noted with an asterisk.

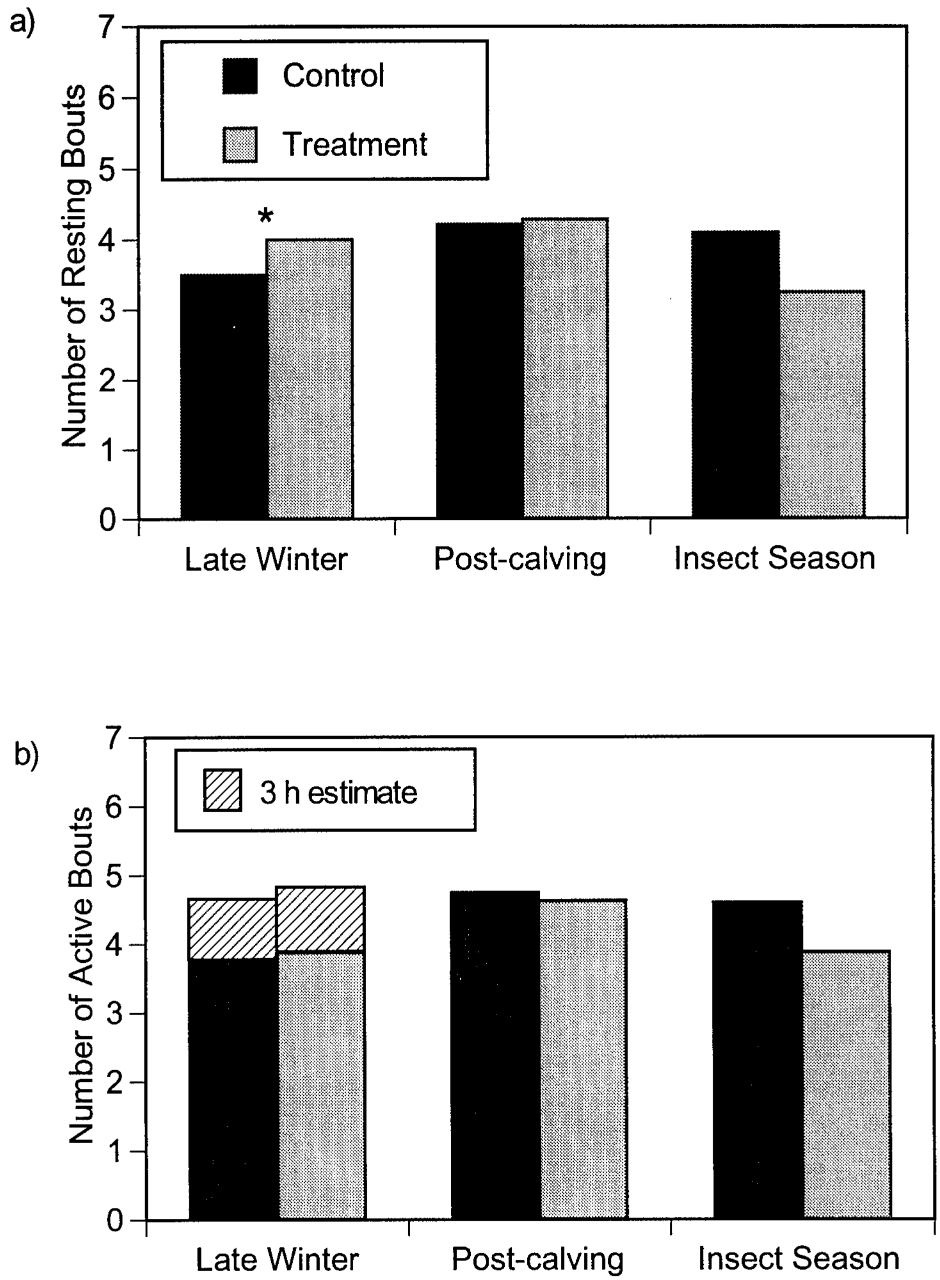

Figure 9. Comparisons (ANOVA) of daily number of a) resting and b) active bouts for control and treatment (i.e. exposed to overflights by low-altitude aircraft) caribou in Alaska, 1991. An asterisk denotes a significant difference between control and treatment groups.

The mean length of resting bouts for animals in the control group ranged from 1.4 to 3.8 h during the three sampling periods (Figure 10a). Mean length of resting bout during the insect season for animals from the treatment group was significantly ($p = 0.02$) shorter than that of the control group (Figure 10a; Appendix B). Despite a similar trend, there were no significant differences during the other two sampling periods. The mean length of active bouts for animals in the control group ranged from 2.3 to 4.6 h (Figure 10b). Mean length of active bouts recorded for animals in the treatment group did not differ ($p = 0.08$) during any of the sampling periods, although there was a consistent trend for animals in the treatment group to have longer active bouts than animals in the control group (Figure 10b; Appendix B). Both treatment and control animals had longer active bouts during the insect season than during the other two sampling periods, with an extreme value of 6.2 h of activity for treatment animals.

Daily time spent resting for animals in the control group ranged from 5.8 to 12.5 h during the three sampling periods (Figure 11a). Animals from the treatment group spent significantly less time resting during post-calving ($p = 0.04$) and the insect season ($p = 0.01$), whereas there was no difference during late winter($p = 0.34$) (Figure 11a; Appendix B). Trends in daily time spent active were the reciprocal of time spent resting. For the control group, daily time active ranged from 11.5 (estimated value) to 18.1 h (Figure 11b). For the treatment group, daily time spent active was significantly greater during post-calving ($p = 0.03$) and the insect season($p = 0.01$) (Figure 11b; Appendix B). A similar trend of greater daily time spent active for overflown animals was apparent during late winter, but the differences in this season were not significant ($p = 0.15$). In the extreme, treatment animals were active for an average of 21 h during the insect season.

Daily activity counts for control animals ranged from 3288 during late winter to 28,179 in the insect season illustrating the substantial seasonal differences in activity. Proportional activity counts (i.e., total counts per day/ total counts per season) for control animals, however, were 0.17 in all seasons (Figure 12). Animals from the treatment group had higher overall daily activity levels (i.e., higher proportional activity counts) only during post-calving ($p = 0.01$). The proportional total count for treatment animals during post-calving was 0.21, which translates to an actual count of 35,051. A similar trend of higher counts for treatment animals also was apparent in late winter, but the difference was not significant (p =0.36).

a)

b)

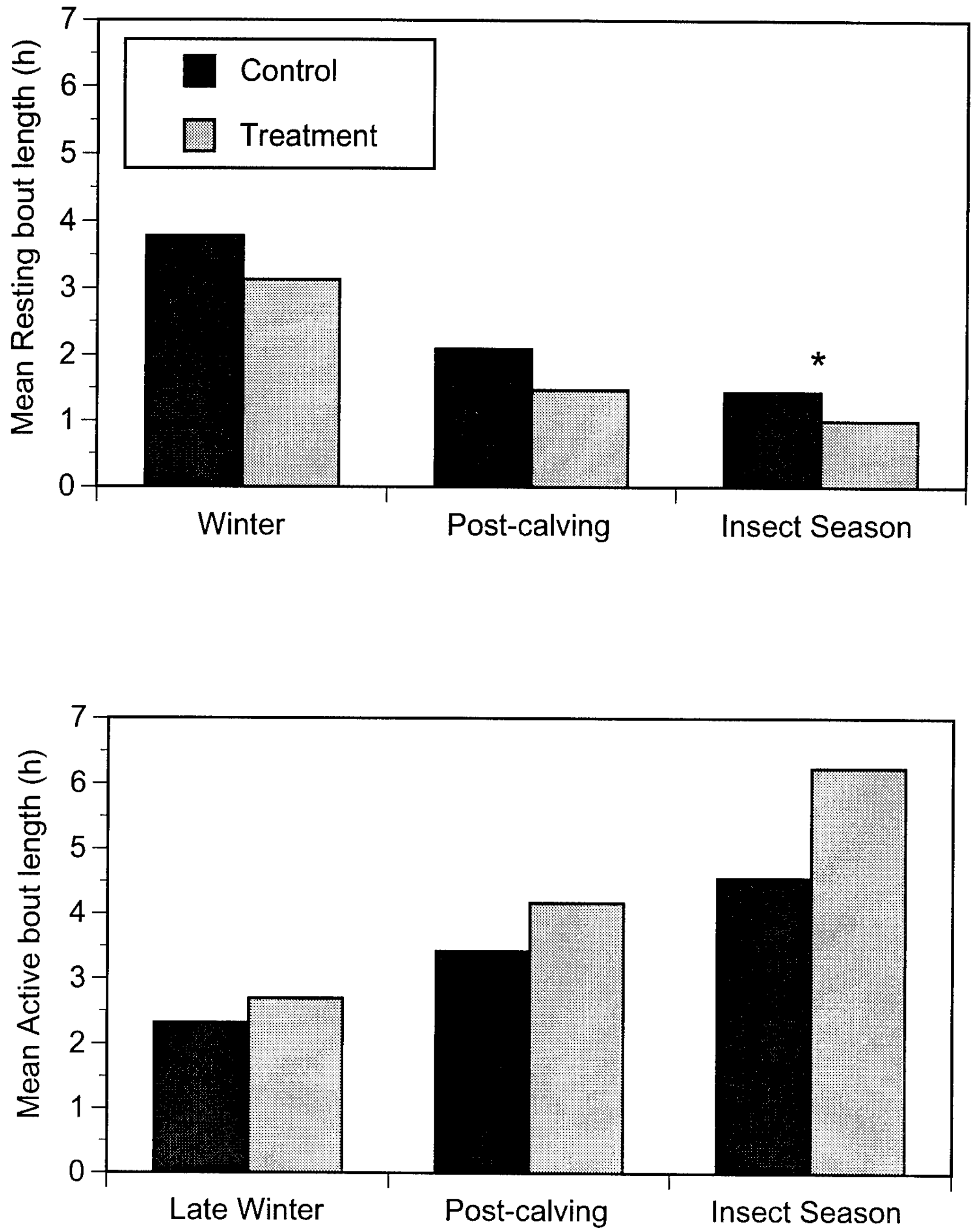

Figure 10. Comparisons (ANOVA) of the mean length of a) resting bouts and b) active bouts for control and treatment (i.e., exposed to overflight by low-altitude jet aircraft) caribou in Alaska, 1991. An asterisk denotes a significance difference between control and treatment groups.

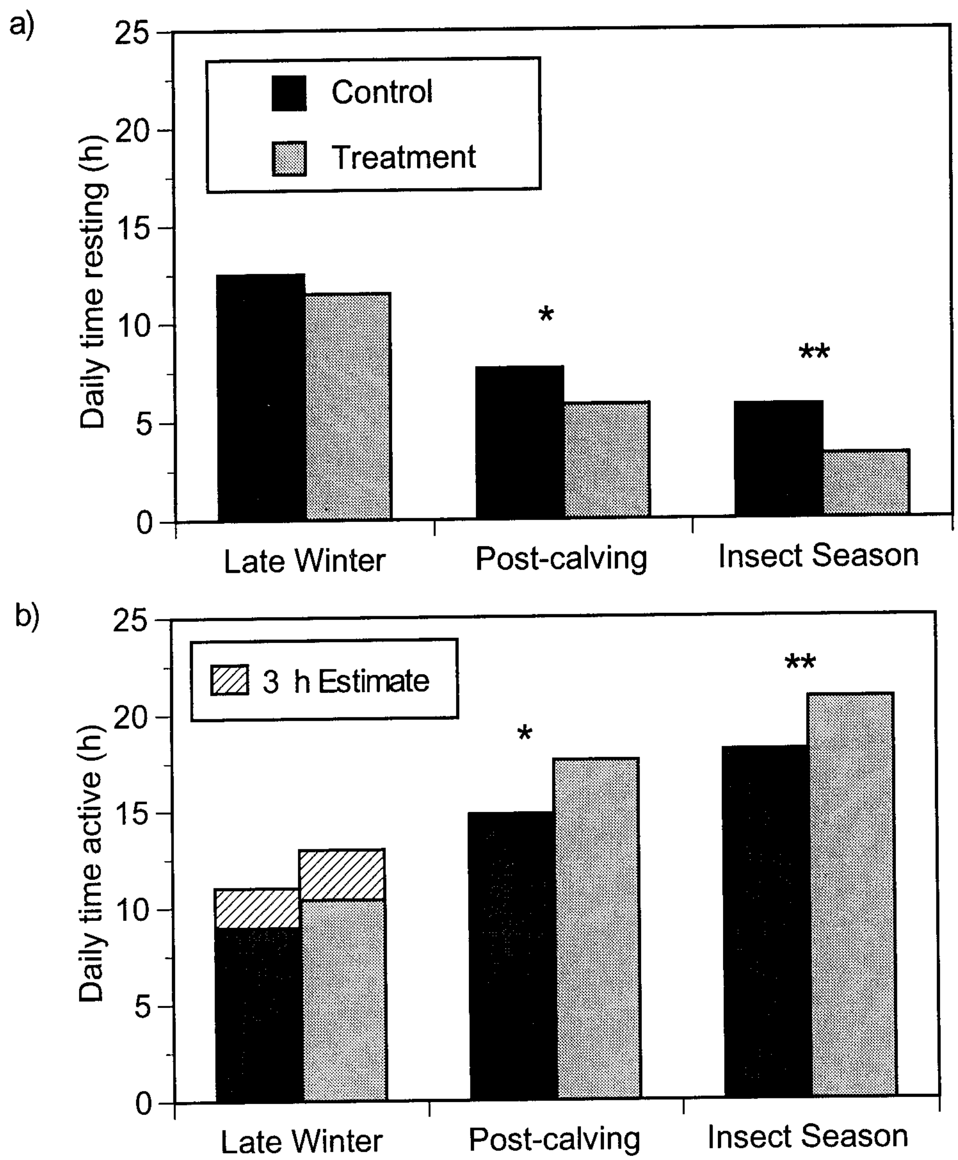

Figure 11. Comparisons (ANOVA) of the total time spent a) resting and b) active for control and treatment (i.e. exposed to overflights by low-altitude jet aircraft) caribou in Alaska, 1991. Number of asterisks denotes the level of significance (i.e., * = $p \leq 0.05$; ** = $p \leq 0.01$) of differences between control and treatment groups.

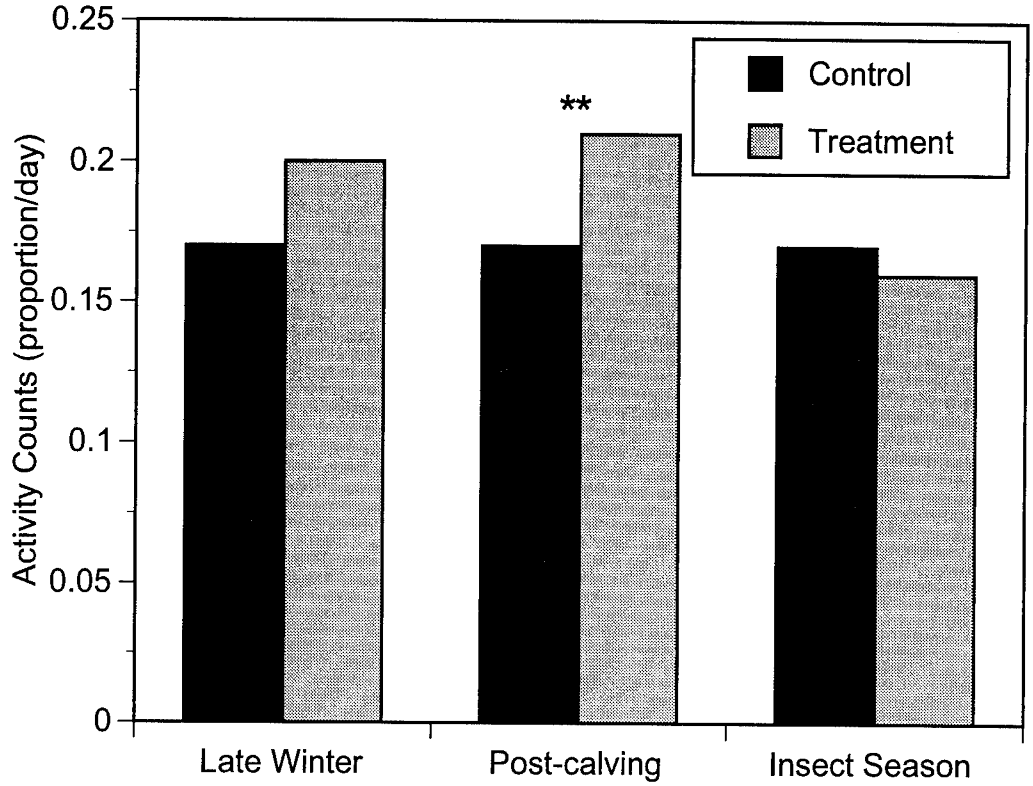

Figure 12. Comparisons (ANOVA) of proportional total counts (i.e. total counts per day/ total counts per season) for control and treatment (i.e. exposed to overflights from low-altitude jet aircraft) caribou in Alaska, 1991. Number of asterisks denotes the level of significance (i.e., * = $p \leq 0.05$; ** = $p \leq 0.01$) of differences between control and treatment groups.

Movements

Distances traveled by animals that were and were not overflown during late winter and the insect season did not differ ($p = 0.48$; $p = 0.45$, respectively) (Figure 13; Appendix B) Animals that were overflown during post-calving, however, traveled significantly farther than did animals that had not been overflown ($p = 0.01$).

Regression Models

The amount of variation in resting cycles and movements of treatment animals attributable to specific aspects of noise was evaluated with regression analysis. The three noise descriptors used as independent variables all were correlated with one another; the loudest overflight of the day and the average noise level (L_T) were highly correlated ($r = 0.98$) in all seasons and the loudest overflight of the day was highly correlated with number of overflights $\geq$85 dBA

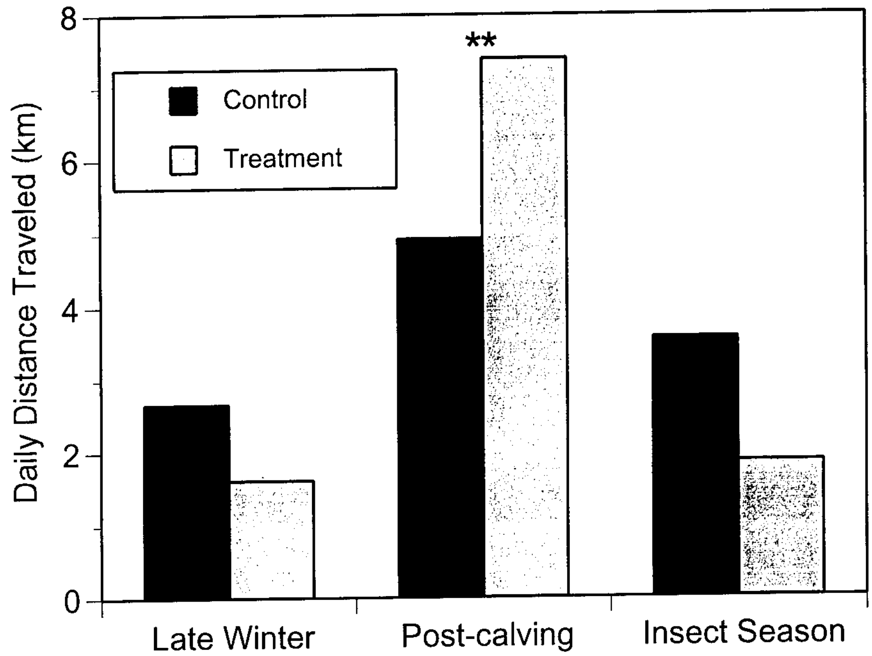

Figure 13. Seasonal comparisons (ANOVA) of daily distance traveled (km) for control and treatment (i.e. exposed to overflights by low-altitude jet aircraft) caribou in Alaska, 1991. Number of asterisks denotes the level of significance (i.e., * = $p \leq 0.05$; ** = $p \leq 0.01$) of differences between control and treatment groups.

per day both during post-calving ($r = 0.70$) and the insect season ($r = 0.79$). This high degree of correlation among independent variables precluded formulation of multiple regression models that included all of these variables. Therefore, simple linear regression analysis relating each dependent variable associated with resting and daily distance moved to each noise variable was used and the best models were retained. Based on Bonferroni corrections, α was assessed at 0.02, rather than at 0.05, for models associated with resting cycles (Table 2) and at 0.05 for models associated with daily movements (Table 3).

During late winter, none of the regression models evaluating the relationship between resting cycles and noise were significant at $\alpha = 0.02$, although all three models could be classified as marginally significant ($0.02 < p < 0.05$; Table 2). In addition, all three models explained approximately 50% of the variation in resting cycles, suggesting that these models may be biologically significant, if not statistically significant.

During post-calving, none of the regression models relating resting cycles to noise were statistically significant ($p \geq 0.08$), and amount of the variation explained by all of the models was low (Table 2). Similarly, none of the models for the insect season were significant

($p \geq 0.12$), although the amount of variation explained by two of the models was approximately 50%.

Regression models relating the daily distance moved by treatment animals to various noise variables were insignificant ($p \geq 0.51$) during late winter and the insect season; however, a highly significant model ($p = 0.003$) was produced during post-calving (Table 3). This model selected the loudest overflight of the day as the best variable for accounting for the variation in daily distance moved ($r = 0.52$). Recall, however, that during post-calving, the loudest overflight of the day was highly correlated with both the number of overflights and the average sound exposure level for the day. Therefore, this model, despite being highly significant, sheds little light on which aspect of noise was affecting caribou.

Table 2. Simple linear regression models evaluating the relationship between various aspects of activity cycles of caribou (dependent variables) and noise exposure (independent variables) resulting from overflights by low-altitude jet aircraft in Alaska, 1991. Simple correlation coefficients (*r*) and test statistics (*F*) were calculated for each model of sample size *n*. Significance (*p*) was evaluated at $\alpha = 0.02$.

Season	Dependent Variable	Model	*r*	*F*	*p*	*n*
Late winter	No. resting bouts/day	$3.53 + 0.061 \times NF$[a]	0.52	5.81	0.03	24
	Mean resting bout	$4.37 - 0.130 \times NF$	0.50	5.63	0.03	24
	Time spent resting/day	$14.0 - 0.032 \times L_T$	0.46	6.98	0.04	24
Post-calving	No. resting bouts/day	$5.09 - 0.084 \times NF$	0.32	3.37	0.08	32
	Mean resting bout	$1.73 - 0.005 \times L_T$	0.17	1.08	0.31	32
	Time spent resting/day	$11.01 - 0.049 \times LOUDSEL$	0.32	3.39	0.08	32
Insect	No. resting bouts/day	$2.51 + 0.050 \times NF$	0.20	0.32	0.59	11
	Mean resting bout	$1.69 - 0.010 \times L_T$	0.50	2.99	0.12	11
	Time spent resting/day	$5.27 - 0.025 \times LOUDSEL$	0.46	2.39	0.16	11

[a] NF = number of overflights $\geq$ 85 dBA in a day.
[b] L_T = average sound exposure level for the day (dBA).
[c] LOUDSEL = loudest sound exposure level (SEL) for the day (dBA).

Table 3. Simple linear regression models evaluating the relationship between daily distance moved by caribou (dependent variable) and noise exposure (independent variables) resulting from overflights by low-altitude jet aircraft in Alaska, 1991.

Season	Model	*r*	*F*	*p*	*n*
Late winter	$18.9 + 0.10 \times L_T$[a]	0.17	0.46	0.51	24
Post-calving	$1.39 + 0.476 \times$ LOUDSEL[b]	0.52	4.72	0.003	32
Insect	$21.2 + 0.07 \times L_T$	0.14	0.18	0.68	11

[a] L_T = average sound exposure level for the day (dBA).

[b] LOUDSEL = loudest sound exposure level (SEL) for the day (dBA).

DISCUSSION

Four aspects of the behavioral responses of caribou to low-altitude overflights were evaluated: instantaneous reactions, activity budgets, activity cycles, and movements. Instantaneous reactions of caribou to overflights were evaluated to determine whether noise intensity, season, or specific types of aircraft influenced the nature of short-term reactions. Activity budgets were evaluated to determine whether the disruptions to behavior truly were short-term or whether the disruptions were sufficient in frequency or duration to alter the overall activity budgets of caribou that were exposed to overflights. The influence of overflights by jet aircraft on daily activity cycles and movements of caribou were addressed to take an even broader view of whether the energetics of the animals, as represented by 24-h feeding and resting cycles and movements, were being influenced by the overflights.

Instantaneous Reactions

Evaluating the instantaneous reactions of caribou to overflights provided the best means of identifying which types and intensities of disturbance caused the greatest disruption of ongoing activity. In general, reactions were mild, seldom involved movement and did not suggest that the animals were panicking or exhibiting predator response behaviors, as described by Bergerud (1974). No differences in reactions among seasons were detected, but F-15s, which were the loudest aircraft, caused stronger reactions than did the other types of aircraft. Noise exposure alone, however, did not explain the variability in duration of reactions or the distance moved in response to overflights. SEL was a poor predictor of the severity of the instantaneous reactions primarily because nearly half (49%) of the groups observed during overflights showed no overt behavioral response to the overflights, regardless of the noise exposure. There are at least two explanations for this variability in responses. One explanation is that reactions differed depending on what the animals were doing at the time of the overflight. That is, if an animal was lying down, an overflight might cause it to get up, or if an animal was standing or feeding, an overflight might cause it to walk, or if an animal was walking at the time of an overflight, it might begin to run when disturbed. An incremental increase in activity associated with overflights would cause variability in the data set similar to what we recorded. Another explanation for the observed variability in reactions to overflights is that there was variability in the responses of individual caribou; that is, some individuals were more tolerant of disturbance than others. Although there are no historical data to directly measure habituation, it appeared that most caribou were habituated to aircraft disturbance. When an experiment such as this one is

conducted, the previous exposure of the subject animals to the stimulus is a critical factor. Habituation, while seldom quantified *in situ*, is a well known phenomenon and must be carefully considered when interpreting the results of behavioral experiments. For this study, it was apparent that the caribou had previously been overflown during routine military exercises in the area and by small, nonmilitary, fixed-wing aircraft. Davis *et al.* (1985) characterized the Delta Caribou Herd as the most highly disturbed herd in Alaska. Thus, caribou in this herd either have habituated or, at least, have had the opportunity to habituate to aircraft disturbance.

Harrington and Veitch (1991) also evaluated short-term impacts of overflights by low-altitude jet aircraft on caribou and found that the jets caused an initial startle response but otherwise brief reactions. Several recent studies also have measured heart rate of wild and captive animals as an indicator of physiological stress due to exposure to aircraft noise (Krausman *et al.* in press; Workman *et al.* 1992a,b,c). Krausman *et al.* (in press) evaluated the effects of simulated low-altitude aircraft noise on heart rate of desert mule deer and desert bighorn sheep and of actual overflights by F-16s on bighorn sheep. In both the simulated and actual overflight experiments, heart rate in deer and sheep increased for some but not all overflights, and the duration of the response was ≤ 2 min even when heart rate was elevated above normal.

Workman *et al.* (1992a,b,c) evaluated heart rate responses of pronghorn antelope, elk, and bighorn sheep to overflights by F-16s (and other stimuli) and concluded that physiological responses of all three of these species were transient and of short duration and that there "appeared to be a process of habituation" to successive overflights. For elk, which might be expected to react similarly to caribou because both species are gregarious Cervids, Workman (1992b) reported that there was very little heart rate response to subsonic overflights by F-16 aircraft. In Workman's study, a person on foot caused greater responses than did the overflights, a phenomenon also observed anecdotally for Delta Herd caribou. In April 1989 at the end of the sampling period, a biologist skied across a valley to retrieve noise monitoring equipment. The same animals that had reacted relatively mildly to A-10 overflights (Murphy *et al.* 1991; Appendix A) became alarmed at the presence of a human and ran for >500 m. These mild responses to aircraft and strong responses to humans may be because humans are perceived as predators and aircraft are not. The aircraft startle the animals in many instances, but they do not appear to evoke a predator avoidance reaction. Humans, by contrast, are predators of Delta Herd caribou during the autumn hunting season, and the animals may be wary for that reason. One reason that reactions of caribou during

post-calving (June) were of interest in this study was that caribou calves often are preyed upon by golden eagles (*Aquila chrysaetos).* Because eagles can only manage to kill young calves, it might follow that cows with calves might be more sensitive to aircraft during this period. Stronger reactions to aircraft by adult female caribou during June were not detected, however.

Activity Budgets

For analysis of 1989 activity data (Murphy *et al.* 1991), 60 min was used as the cutpoint for distinguishing between animals that had recently been overflown and animals that had not. An analysis of the data from late winter 1991 using a 60-min cutpoint was included for comparative purposes and the same result was obtained; caribou exposed to overflights fed significantly ($p \leq 0.05$) more and rested substantially ($p \leq 0.10$) less than did unexposed animals. However, based on the results of the instantaneous reactions of caribou to overflights in 1991, it was apparent that overt behavioral responses were short-term in nature and that 60 min may be too long to consider an animal to be potentially disturbed by overflights. In addition, the work on heart rate responses of ungulates to overflights reported on by Krausman *et al.* (in press) and Workman *et al.* (1992a,b,c) provides further evidence that reactions are short-term in nature. Therefore, in analyzing the activity data from 1991, we used both 60 min and the shorter time period of 15 min for comparative analyses. The 60-min time period offers comparability with 1989 results, but the 15-min time period probably represents a more biologically meaningful cutpoint.

Based on the 15-min time period, tests results indicated that overflights altered activity budgets during two of the three sampling periods. During late winter, no differences in the activity budgets of caribou that had been recently overflown were detected, whereas differences were apparent during post-calving and the insect season. During both the post-calving and insect seasons, caribou that had been overflown during the previous 15-min period spent significantly ($p \leq 0.001$) less time lying than did caribou that had not been overflown. A decrease in time spent lying by caribou in response to disturbance has been interpreted to be a subtle, low-intensity response by animals that are aware of a disturbing stimulus and are able to go about most of their normal activities, but are not comfortable enough to lie down (Murphy and Curatolo 1987).

In 1989, differences in time spent feeding and lying between animals that had recently been overflown (60 min) and animals that had not been overflown were detected, with disturbed animals feeding more and lying less (Murphy *et al.* 1991). These same differences in winter

1991 were not detected using the 15-min time period, but were detected when the 60-min time period was used. The results from the post-calving and insect seasons using the 60-min time period also differed from those generated with the 15-min time period. These differences are not entirely reconcilable. It is noteworthy, however, that the 15-min data set was better suited for statistical analyses because there was a more even distribution of samples between the two time periods being contrasted. Overall, we have more biological and statistical confidence in the results of the analyses based on 15-min; therefore, we think that effects on activity were minimal during late winter and more substantial during post-calving and the insect season.

Activity Cycles

Of the seven variables related to activity cycle (i.e., number of resting and active bouts, mean duration of resting and active bouts, daily time spent active and resting, and daily activity counts), duration of bouts and daily time spent active and resting were the most useful variables for assessing effects of overflights. These activity variables most accurately reflected the way that caribou balance energy intake with output. The other variables also were useful for interpretation, however.

Based on the activity cycles of undisturbed caribou (i.e., control animals), it was clear that caribou were least active during late winter, more active during post-calving, and most active during the insect season; daily time spent active for control animals averaged 11.2, 14.8 and 18.1 h, respectively, during these three sampling periods (Figure 11b). These seasonal differences in activity patterns have been well documented for numerous herds throughout North America (Russell *et al.* 1993) and basically result from seasonal differences in environmental conditions (e.g., snow depth, insect activity) and the presence of neonatal calves in early summer. Because of these natural seasonal differences in activity patterns, it was important to evaluate responses to disturbance on a seasonal basis to identify potentially sensitive times of the year.

Although the intensity of responses to low-altitude overflights differed by season, treatment animals exhibited consistent trends of increased activity and decreased resting compared to control animals during all three sampling periods. In late winter, a significant increase in the number of daily resting bouts (Figure 9a) was associated with a near significant increase in mean active bout duration (Figure 10b). The trend toward increasing activity by treatment animals was stronger during post-calving and resulted in a significant decrease in daily time spent resting (Figure 11a) and a 2.8 h increase in daily time spent active (Figure 11b). Daily

activity counts of treatment animals during post-calving also increased compared to control animals (Figure 12). During the insect season, treatment animals had shorter resting bouts (1.4 h) and longer active bouts (3.4 h) than did control animals. Daily time spent active for treatment animals (20.1 h) was at an extreme for all conditions evaluated (Figure 11b). Thus, although instantaneous behavioral responses to overflights were mild, the cumulative effect of overflights was evident in daily activity cycles.

Movements

Daily movements were evaluated to determine whether treatment animals would respond to overflights by jet aircraft by traveling farther than control animals. Distance traveled did not differ between treatment and control animals during late winter, perhaps because snow can provide significant resistance to movement (Fancy and White 1985) and/or caribou were less responsive to disturbance at this time of year. Milder reactions in late winter also could be associated with the fact that calves were nearly a year old and were less vulnerable to disturbance at this time of year.

During post-calving, treatment animals traveled significantly farther than did control animals, and these results indicate that the presence of newborn calves in June may cause female caribou to respond more strongly to disturbance than at other times of the year. This increased movement during post-calving corresponds with the increased activity level discussed previously and suggests that disturbed caribou with young calves are more likely to move in response to disturbance than at other times of the year. Although increased locomotion in response to overflights was not detected in analyses of caribou activity budgets (Figures 7 and 8), data on movements showed that a 10 dBA increase in maximum noise exposure for the day was associated with a 4.8 km increase in distance moved. There are no data to evaluate whether treatment animals during post-calving were trying to move from the disturbance zone, however, Dau and Cameron (1986) demonstrated that caribou with neonatal calves will avoid areas with disturbing stimuli.

The increased movement observed during post-calving probably was of low energetic cost because the caribou moved only an additional 2.5 km/d and the energetic costs of locomotion for caribou are lower than any other ungulate evaluated to date (Fancy and White 1987). However, if the caribou moved to less productive habitat there would be additional energetic costs, as was demonstrated for bighorn sheep (Bleich *et al.* 1990). In addition, it has been shown that small changes in habitat quality can have multiplicative effects on caribou productivity (White 1983). Changes in distance moved and habitat use also may

change the probability of encountering predators. Predation on Delta Herd caribou by wolves (*Canis lupus*) and other predators has been at a high rate in recent years (Valkenburg 1992), and if overflights are increasing the chances that caribou will encounter predators, then this potential consequence of aircraft disturbance should be investigated more thoroughly.

Distance traveled during the insect season also did not differ between treatment and control animals, but activity counts were significantly higher for treatment animals during this season. These results suggest that movements during the insect season were not directional and that the net distance traveled might not accurately describe caribou responses to aircraft disturbance during this season. In addition, insect harassment of caribou causes an increase in daily activity (White *et al.* 1975, Murphy and Curatolo 1987, Russell *et al.* 1993) to such an extent that a further increase in activity due to other stressors may not be detectable.

Regression Models

Models of daily resting cycles from activity counts and daily movements of treatment animals regressed against three measures of noise exposure were developed to evaluate whether any specific aspect of noise was responsible for observed variations in behavior or movements. These were not strong analyses because the noise variables were highly correlated with one another. Consequently, we did not identify any particular aspect of noise that could be identified as affecting caribou more than the others. For the one highly significant model that we did develop (i.e., daily movements during post-calving; Table 3), the loudest overflight of the day was most highly correlated with variation in daily movements.

Converting activity budgets to an energy currency is one method used to quantitatively assess the energy costs of exposure of caribou to overflights by low-altitude jet aircraft. Analyses of energy expenditure can be used to make quantitative impact assessments, and this is the subject of a separate report (White *et al.*, in review). This analysis of energetic costs of aircraft disturbance will use activity counts to assess daily energy expenditures. Data from regression analysis then are used to determine possible reproductive consequences of increased energy costs due to overflights. The process is made possible by adapting an existing caribou energetics model (Kremaster *et al.* 1989, White 1991, Russell *et al.* 1993) to operate through a set of rules that link overflights by jet aircraft to a daily activity budget.

CONCLUSIONS

Seasonal differences in activity and movement patterns were evident for undisturbed caribou indicating that the annual activity cycle of caribou is complex. The behavioral responses of caribou to low-altitude overflights by jet aircraft also varied seasonally indicating that impact analyses must consider these different sources of variation. During late winter, caribou naturally were moving less because of the high energetic cost of traveling through snow and, accordingly, their response to disturbance did not entail increased movement. Overall, reactions to overflights were mild during this season.

During post-calving, activity levels of undisturbed caribou were intermediate between the other two seasons, but responses to overflights were most pronounced during this season. Aircraft disturbance caused cow-calf groups to respond by increasing activity and movements, which could result in movements to suboptimal habitats or greater chances of encountering predators.

During the insect season, undisturbed caribou were more active and moved more than did caribou during the other two seasons that were evaluated. Caribou that were overflown by jet aircraft showed an increase in activity, but this was not accompanied by an increase in daily distance traveled. Thus, caribou during the insect season were less responsive to overflights than were caribou during post-calving, but were more responsive than were caribou during late winter.

Overall, the results of this study indicate that instantaneous reactions were mild, but that modifications of activity budgets, activity cycles, and daily movements were evident for caribou exposed to overflights. For the three seasons that were evaluated, the severity of the responses to overflights was inversely related to the age of the calves accompanying the females under study (i.e., responses were most prevalent when young calves were present). Therefore, we conclude that females with young are more sensitive to aircraft disturbance.

Energetic and demographic consequences of behavioral responses to aircraft disturbance are unquantified at this time. The field data collected for this evaluation of behavioral responses will be incorporated into an energetics model (previously described) that will predict the energetic and population consequences of repeated overflights.

The results of this study may have been considerably different if we had chosen to work with a herd that had little or no previous exposure to overflights by low-altitude jet aircraft. Notwithstanding, we think using the Delta Herd as study subjects addressed the most

germane questions regarding chronic disturbance in a military operations area that overlaps the range of a herd of ungulates. That is, if the ultimate question is long-term population effects, then studying the effects of military training exercises on animals that have had an opportunity to habituate best addresses what the nature and extent of long-term impacts are likely to be.

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APPENDIX A. Results of 1989 Study.

BEHAVIORAL RESPONSES OF DELTA HERD CARIBOU TO LOW-LEVEL, SUBSONIC JET AIRCRAFT OVERFLIGHTS

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EXPANDED ABSTRACT

In April 1989, we initiated the first phase of a U.S. Air Force-sponsored research program designed to quantify the behavioral and physiological responses of caribou (Rangifer tarandus granti) to low-level sub-sonic jet aircraft overflights, and to incorporate these findings into a model that can predict the energetic consequences of repeated overflights. The goal of this first phase was to evaluate the feasibility of implementing the field aspects of this program using a wild population of free-ranging caribou; the Delta herd of central Alaska was chosen as the study population.

The aircraft used were A-10s from Eielson Air Force Base and most overflights were flown at 100-150 m agl. The activity budgets of animals in focal groups were monitored before and after overflights, and the instantaneous reactions of these groups were recorded during the controlled disturbance events. Three noise meters (Larson-Davis Model 870) were positioned in the study area to estimate the noise exposure levels that the animals experienced.

We recorded 811 instantaneous reactions of caribou to 107 overflights by 72 A-10 aircraft (some overflights passed over more than one group of caribou). Twenty-two percent of the caribou had an overt behavioral reaction to the overflights; 18% became alert, 2% changed activity from lying to standing, and 2% walked or ran (Figure A-1). Seventy-eight percent of the caribou showed no overt behavioral reaction to the overflights.

Undisturbed caribou (i.e., before overflights) spent approximately 50% of their time feeding, 40% lying, and 10% standing and walking (Figure 2). Although there were few strong instantaneous reactions to overflights, activity budgets of caribou after overflights were substantially different than before. The most pronounced differences were that after

overflights caribou spent more time feeding and less time lying, although total time engaged in these two activities was similar (approx. 95%) before and after.

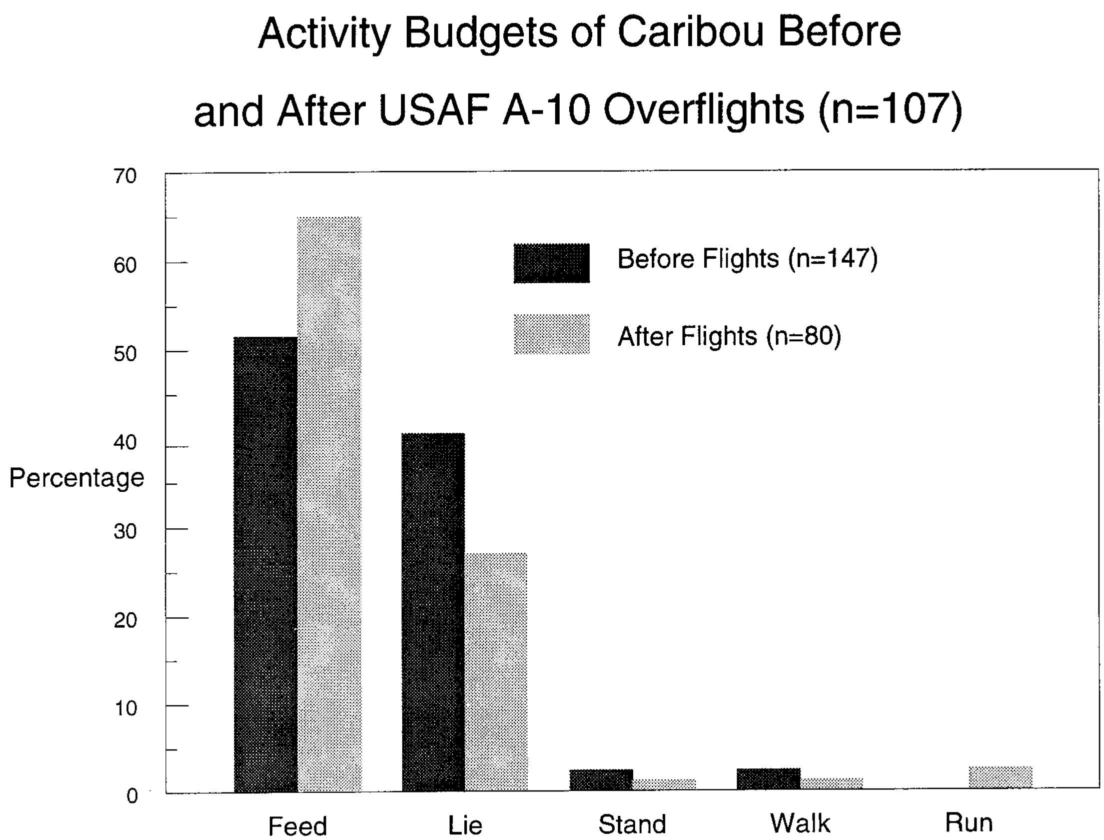

Figure A-1.

The maximum L_{eq} measured was 98.7 dB(A), which occurred during a direct overflight at 100 m altitude. A-10's produce sound pressure levels that are relatively low compared with those produced by most military jet aircraft, and this combined with the regular exposure of Delta Herd caribou to military training flights, may account for the mild behavioral responses that we observed.

In 1990, we will conduct overflights during late-winter (April), post-calving (early June), and the insect season (July). We hope that at least a portion of the overflights will be flown using louder F-series aircraft. In addition to the behavioral information described here, we also will equip five cow caribou with heart-rate monitors and noise dosimeters. These data will be used to verify an energetics model derived from experiments with captive caribou at the Large Animal Research Station, University of Alaska—Fairbanks.

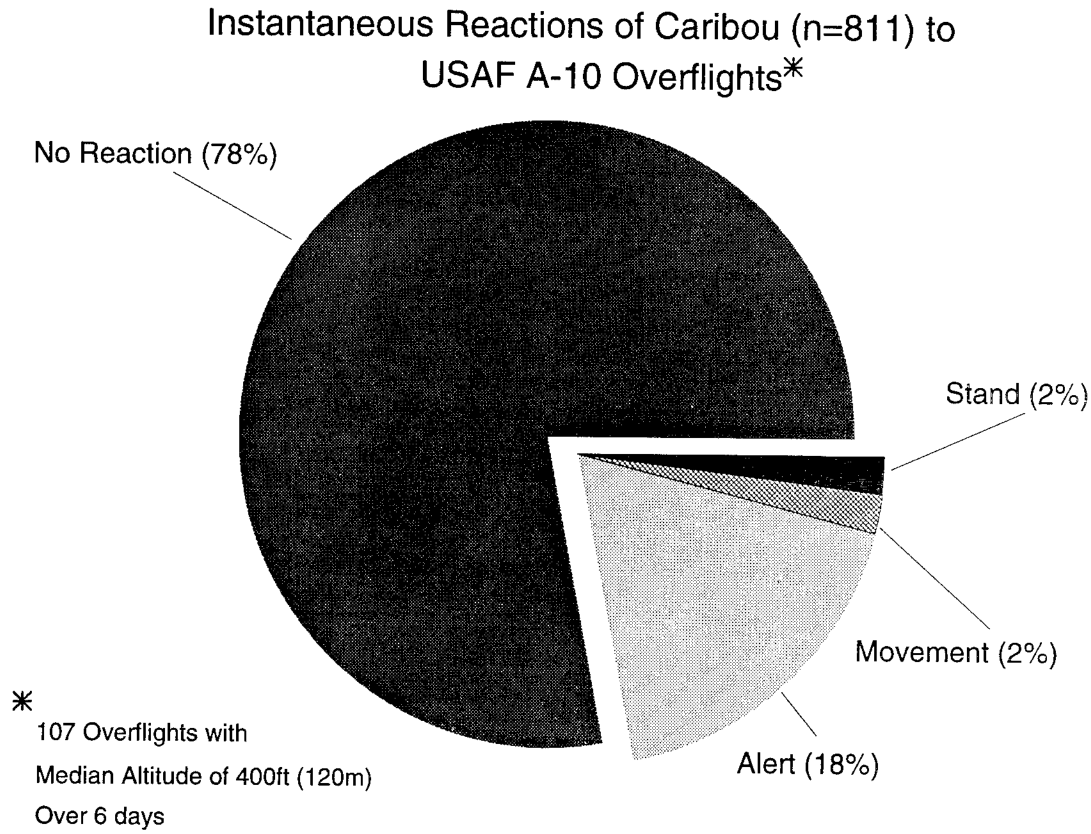
Instantaneous Reactions of Caribou (n=811) to
USAF A-10 Overflights*
No Reaction (78%)
Stand (2%)
Movement (2%)
Alert (18%)
*
107 Overflights with
Median Altitude of 400ft (120m)
Over 6 days

Figure A-2.

APPENDIX B. Hypotheses and Results of Statistical Analyses.

INSTANTANEOUS REACTIONS

H_o: Instantaneous reactions did not differ among types of aircraft or among seasons (Figure 5).

	p value				
	None	Alert	Stand	Move	*n*
Aircraft	0.001	0.032	0.521	0.290	158
Season	0.339	0.053	0.300	0.830	158

H_o: The distance moved by animals reacting to overflights did not vary as a function of SEL (Figure 6a).

Anova Table	DF	SS	MS	*r*	Adj r^2	SE
Regression	1	55.78	55.78	0.065	-0.024	19.34
Residual	35	13104.5	374.41			

Factor	β	SE β	T	*p*	*n*
SEL	0.135	0.339	0.386	0.702	36
Distance moved	-0.956	35.01	0.048	0.962	36

H_o : The duration of reactions to overflights did not vary as a function of SEL (Figure 6b).

Anova Table	DF	SS	MS	*r*	Adj r^2	SE
Regression	1	14.27	14.27	0.018	-0.0066	17.87
Residual	144	46019.4	319.57			

Factor	β	SE β	T	*p*	*n*
SEL	0.000476	0.135	0.211	0.833	145
Duration of reaction	0.165	13.50	0.731	0.466	145

H_o: The proportion of animals engaged in various activities did not differ before and after overflights (Figure 7).

	p value				Sample size	
SEASON	Feed	Lie	Stand	Walk	Before	After
Late winter	0.686	0.685	0.679	0.884	35	71
Post-calving	0.176	0.622	0.663	0.142	10	22
Insect	0.108	0.305	0.704	0.674	15	25

ACTIVITY BUDGETS

H_0: The time spent engaged in various activities (feeding, lying, standing, walking, running) did not differ between animals that had been exposed recently to jet aircraft overflights and animals that had not been exposed recently (60 min) (Figure 8a).

Season	*p* value				Sample size	
	Feed	Lie	Stand	Walk	Exposed	Unexposed
Late winter	0.028	0.066	no data	0.447	58	105
Post-calving	0.198	0.641	no data	0.691	28	36
Insect	0.934	0.000	0.000	0.266	125	72

H_0: The time spent engaged in various activities (feeding, lying, standing, walking, running) did not differ between animals that had been exposed recently to jet aircraft overflights and animals that had not been exposed recently (15 min) (Figure 8b).

Season	*p* value				Sample size	
	Feed	Lie	Stand	Walk	Exposed	Unexposed
Late winter	0.136	0.417	0.436	0.261	58	105
Post-calving	0.000	0.001	0.051	0.230	28	36
Insect	0.212	0.000	0.014	0.834	125	72

ACTIVITY CYCLES

H_o: The number of resting and active bouts per day was not dependent on whether caribou had been exposed to low-altitude overflights (Figure 9).

Activity variable / Season	Sample size: Treatment	Sample size: Control	p
Number of resting bouts			
Late winter (21 h)	16	17	0.05
Post-calving	28	34	0.87
Insect	8	33	0.20
Number of active bouts			
Late winter (21 h)	16	17	0.59
Post-calving	28	34	0.76
Insect	8	33	0.19

H_o: Mean length of active and resting bouts was not dependent on whether caribou had been exposed to low-altitude overflights (Figure 10).

Activity variable / Season	Sample size: Treatment	Sample size: Control	p
Mean length of resting bouts			
Late winter (21 h)	16	17	0.22
Post-calving	28	34	0.11
Insect	8	33	0.02
Mean length of active bouts			
Late winter (21 h)	16	17	0.08
Post-calving	28	34	0.12
Insect	8	33	0.08

H_o: Daily time spent resting and active was not dependent on whether caribou had been exposed to low-altitude overflights (Figure 11).

Activity Variable / Season	Sample size		p
	Treatment	Control	
Daily time spent resting			
Late winter (21 h)	16	17	0.34
Post-calving	28	34	0.04
Insect	8	33	0.01
Daily time spent active			
Late winter (21 h)	16	17	0.15
Post-calving	28	34	0.03
Insect	8	33	0.01

H_o: The overall activity level of caribou was not dependent on whether caribou had been exposed to low-altitude overflights (Figures 12 and 13).

Activity Variable / Season	Sample size		p
	Treatment	Control	
Proportional daily counts			
Late winter (21 h)	16	17	0.36
Post-calving	28	34	0.01
Insect	8	33	0.57
Daily distance traveled			
Late winter (21 h)	19	18	0.48
Post-calving	21	21	0.01
Insect	33	7	0.45

U. S. Government Printing Office 1995 650-075/00042